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HOUSE DAMAGE ASSESSMENT

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13. ABSTRACT

During the past 21 years, a series of tests has been conducted in which a variety of residential dwellings were exposed to the air blast from high explosives and nuclear events. These tests were sponsored by several different agencies, including the Defense Nuclear Agency, the Atomic Energy Commission, the Department of Defense Explosives Safety Board, and the Defense Civil Preparedness Agency.

The purpose of this project was to review the reports and data from these tests and summarize the available house damage data, and to develop means by which the house damage could be evaluated. House damage is reported by the type of house, the test location, the charge type and size, the peak overpressure, and ground range. A summary of the data and means for evaluating the damage both objectively and subjectively are presented. To supplement the house test data, additional static test data, and data for wall panel tests conducted in the URS Shock Tunnel for the Defense Civil Protection Agency are included.

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Summary Report

HOUSE DAMAGE ASSESSMENT

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Engineering Research Division

HEADQUARTERS
Defense Nuclear Agency
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ILLUSTRATIONS (cont.)

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ILLUSTRATIONS (cont.)

TABLES

Section 1

INTRODUCTION

During the past 21 years, a series of tests has been conducted in which a variety of residential dwellings were exposed to the air blast from high explosives and nuclear events. These tests were sponsored by several different agencies, including the Defense Nuclear Agency (DNA), the Atomic Energy Commission (AEC), the Department of Defense Explosives Safety Board (DODESB), and the Office of Civil Defense (OCD), now the Defense Civil Preparedness Agency (DCPA).

The purpose of this project was to review the reports and data from these tests and summarize the available house-damage data, and to develop means by which the house damage could be evaluated.

The houses discussed in this report are separated into the following categories:

- Type I — Two-story, center-hall, wood frame house with a full basement
- Type II — Two-story, brick and concrete block, center-hall house with a full basement
- Type III — One-story, wood-frame, ranch-style house on a concrete slab foundation
- Type IV — Two-story, brick apartment house with heavy shear walls (European-type construction)

Sub-categories of these houses are as follows:

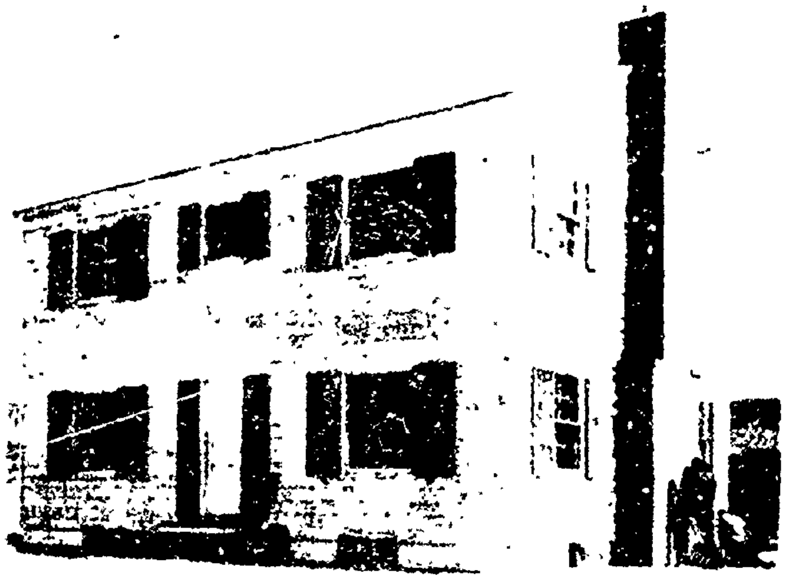
- Strengthened (blast resistant) versions of above types, and
- Repaired houses which had previously sustained blast damage.

A summary of the tests and houses which are included in this study is presented in Table 1-1. Included in this table are the type of house, the test location, the charge type and size, the peak overpressure, and ground range.

REPORT ORGANIZATION

It will be noted in Table 1-1 that the majority of tests were conducted on the Type I house, a two-story, wood frame structure. A description of this type of house and the data from the tests with this house are presented in Section 2. Similar data for Types II, III, and IV structures are presented in Sections 3, 4, and 5, respectively. A summary of the data from all the houses and means for evaluating the damage both objectively and subjectively are presented in Section 6. To supplement the house-test data, additional static test data, and data for wall panel tests conducted in the URS Shock Tunnel for the Defense Civil Preparedness Agency are included in Appendix A.

A special report on damage to miscellaneous structures during Operation Castle is presented in Appendix B.



Front View

Right Side

Fig. 2-1 Photographs of Type I House

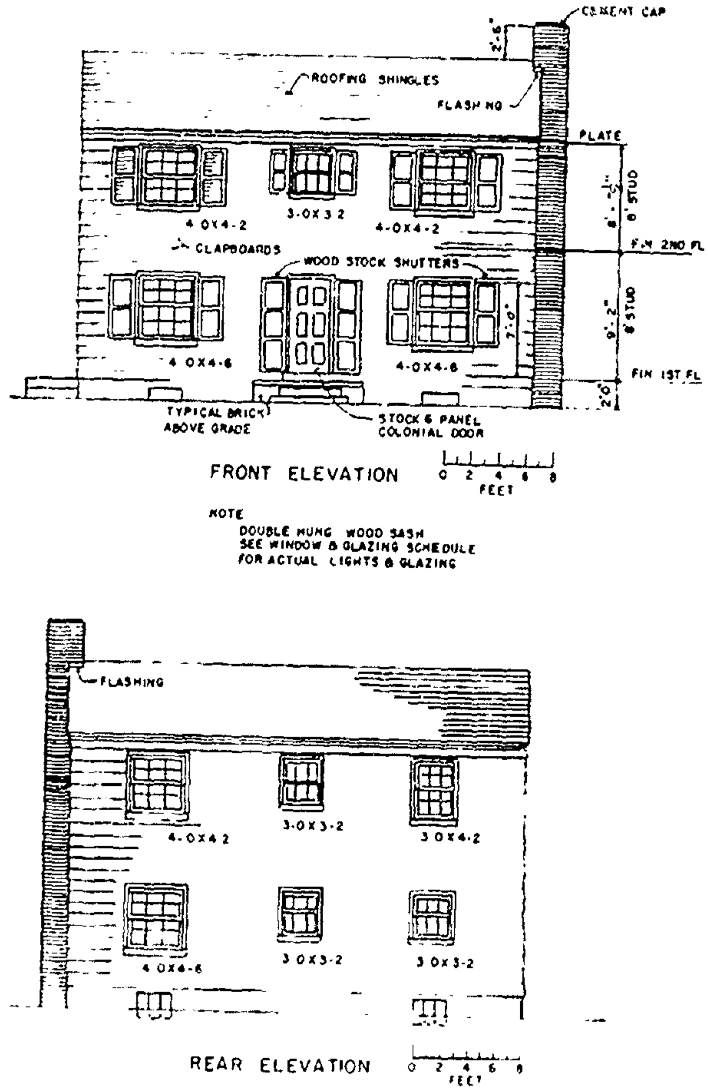
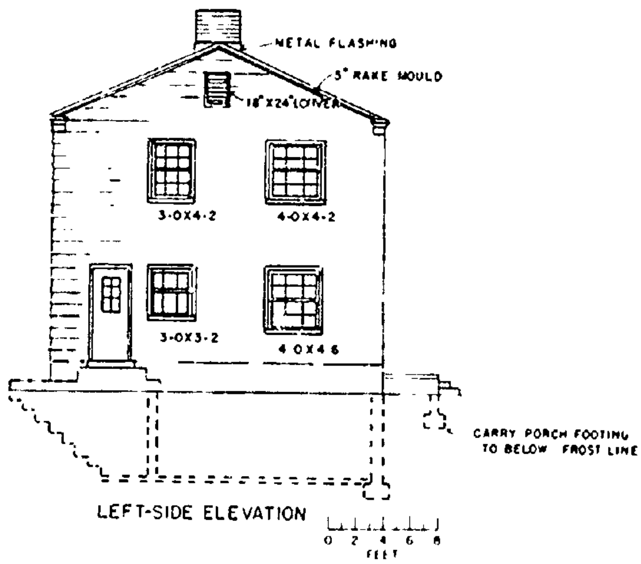
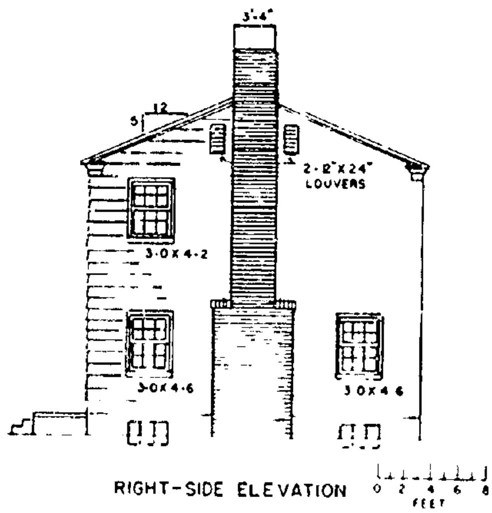


Fig. 2-2. Elevations of Type I House



LEFT-SIDE ELEVATION



RIGHT-SIDE ELEVATION

Fig. 2-2 (cont.)

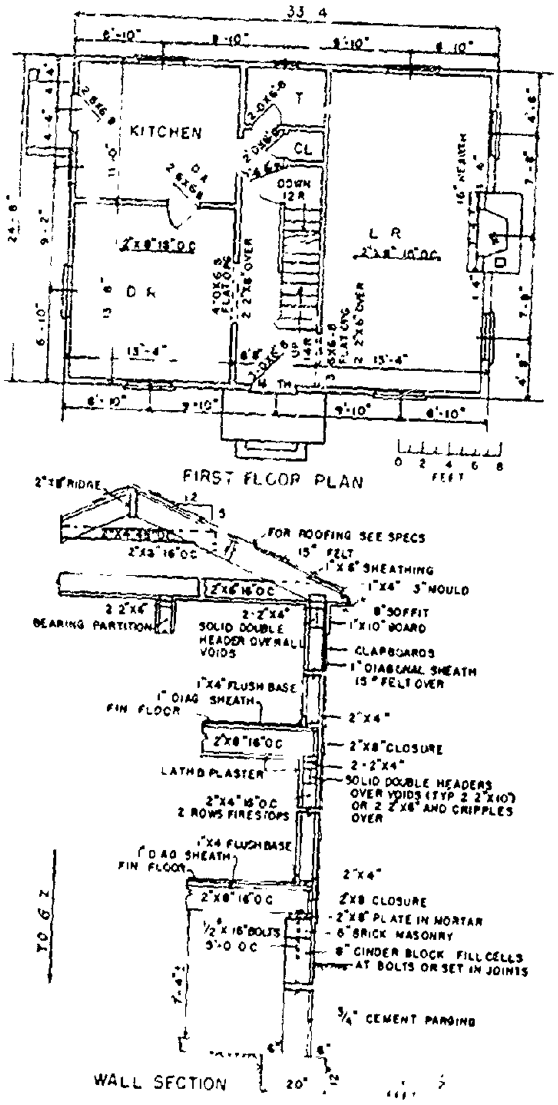
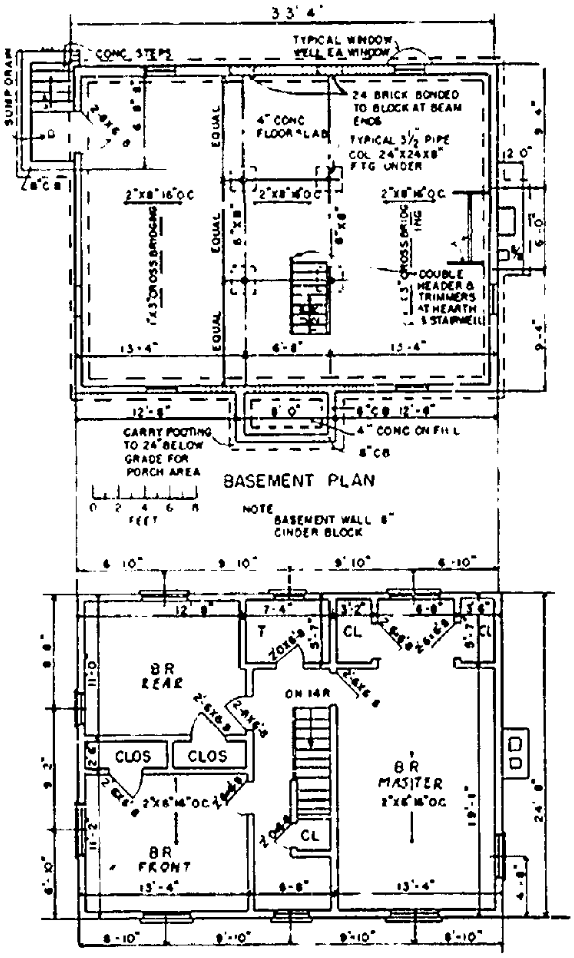


Fig. 2-3. Construction Drawing, Type I House



SECOND FLOOR PLAN

Fig. 2-3 (cont.)

Sole plate to joist or blocking	20d-16 in. o.c.
Top plate to stud, end-nail	2-16d
Stud to sole plate, toe-nail	3-16d
Double studs	16d-30 in. o.c.
Top plates, spiked together	16d-24 in. o.c.
Laps and intersections	3-16d
To parallel alternate rafters	3-16d
Rafter to plate	3-16d
1- by 8-in. sheathing or less, to bearing	2-8d
Over 1- by 8-in. sheathing, to bearing	3-8d
Corner studs and angles	3-8d
Other joists, nail to provide proportionate strength	

Headers over openings shall be not less than the following sizes:

Size	Max. span (in.)
Two 2 by 4's on edge	3 ft 6
Two 2 by 6's on edge	4 ft 6
Two 2 by 8's on edge	6 ft 0
Two 2 by 10's on edge	7 ft 6

Interior walls shall have 3/8-in. gypsum lath nailed direct to wood studs and have one coat of gypsum plaster 3/8-in. thick.

TEST DESCRIPTIONS AND RESULTS

As noted in Table 1-1, a total of 11 tests were conducted with the Type I, two-story, wood frame house. Four of the houses were exposed to the air blast from nuclear devices, and the remaining 7 to the air blast from various quantities of high explosives, ranging in size from approximately 2500 lb to 500 tons. These tests are summarized below.

NUCLEAR TESTS		
HOUSE NO.	CHARGE SIZE (kt)	PEAK OVERPRESSURE (psi)
I-1	16.4	1.7
I-2*	16.4	5.0
I-3*	30.0	4.0
I-4	30.0	2.6

* These were strengthened versions of the Type I house.

HIGH EXPLOSIVE TESTS		
HOUSE NO.	CHARGE SIZE (lb)	PEAK OVERPRESSURE (psi)
I-5	10,000	1.3
I-6	10,000**	1.2
I-7	1,000,000	1.5
I-8	200,000	1.6
I-9	1,000,000	2.7
I-10	2,550	
I-11	3,500	

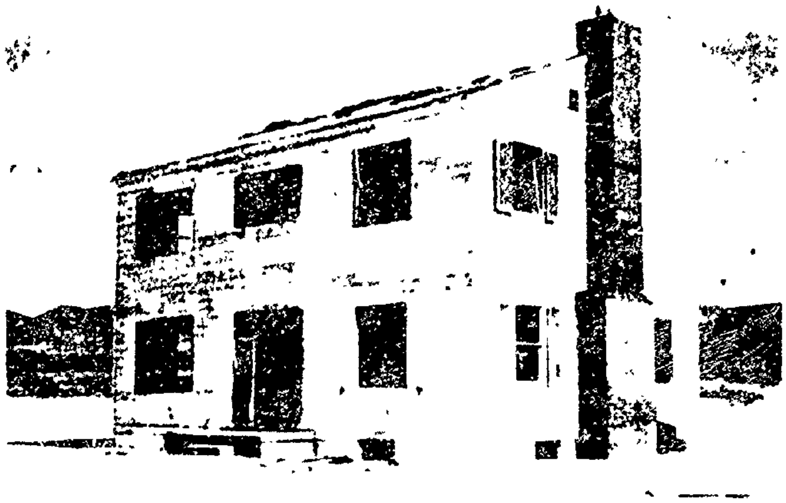
** Two 5000-lb charges detonated approximately 20 msec apart.

Test Description, Houses I-1 and I-2

In 1953, during Operation UPSHOT-KNOTHOLE, two Type I houses were exposed to a 16.2 kt nuclear device (Annie) exploded at an altitude of 300 ft. These houses were constructed as described in the specifications given earlier in this section. The test results were obtained primarily from Ref. 1.

Test Results, House I-1

This house was located at 7500 ft from ground zero where the incident peak overpressure was 1.7 psi. Post-test photographs of the exterior of the house are presented in Fig. 2-4. Doors, windows, and window frames were either blasted out of the walls or remained in place in a badly damaged condition. In general, the window glass was shattered into small particles and scattered uniformly about the exterior of the house. The only windows



Front and Right Side

Rear and Right Side

Fig. 2-1. Post-Test Photos, House I-1

remaining intact were four windows at the rear of the house which were sheltered by interior partitions, and the rear basement windows, which were blown open inwardly. The majority of the 2- by 8-in. floor joists of the front floor system were undamaged. Exceptions were a broken joist under the kitchen, three broken joists under the dining room, and the damage under the living room as shown in Fig. 2-5.

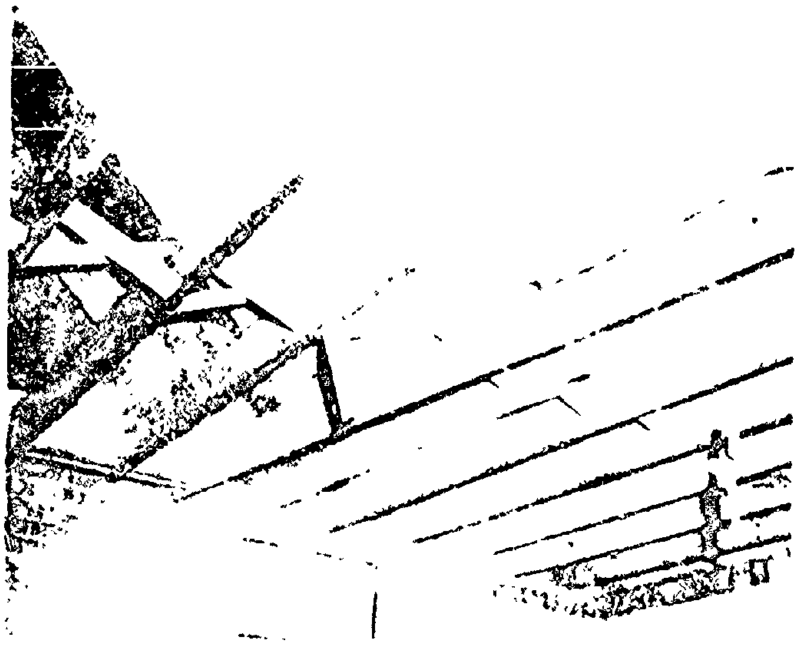
The joists framing into the double header were designed to be supported by steel joist hangers but were only spiked to the headers. These nails bent, allowing the supported joists to drop about 3 in. at the support, splitting one joist and pulling out the nails that secured the subflooring to the joists. The trimmers were shown on the architectural drawings as being doubled, but in the construction they were single joists and one failed in horizontal shear and one in bending.

Figure 2-6 shows the extensive plaster damage and the one broken first floor stud. This is a view of the area near the front entrance, taken from the living room. Plaster cracks around the fireplace indicated that there had been some inward deflection of the studs in this area.

The kitchen in the rear of the house was protected somewhat by the partition wall between it and the dining room, yet furniture was thrown about. The door to the dining room was broken and portions of it were embedded in the plaster of the rear wall, as shown in Fig. 2-7. The kitchen wall on the side of the house between the door and window, bulged slightly inward, causing plaster cracks. The studs in this part of the wall may have been broken.

Figure 2-8 is a view of the master bedroom after the blast, looking toward ground zero. Deflection and splitting of the second story studs in the front wall caused considerable plaster damage in this room. Damage to the ceiling may have been caused by unequal pressures in the attic and second story, or by the weakening of the plaster due to blast, with later removal by the wind. In the front bedroom one broken stud was noted; and judging from the horizontal plaster crack, it is probable that other studs were split.

Front Floor Joists



Rear Floor Joists

Fig. 2-5. Floor Joist Damage Under Living Room, House I-1

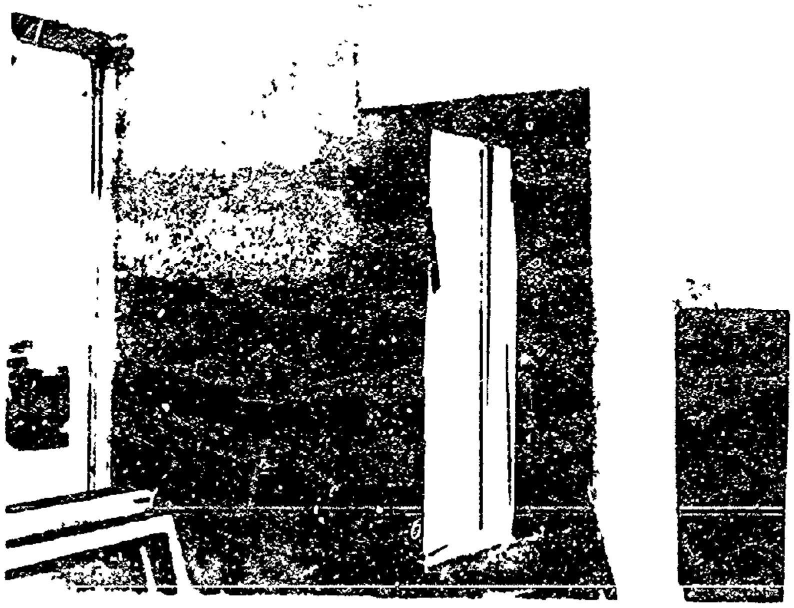


Fig. 2-6. Living Room, Near the Front Entrance, House I-1

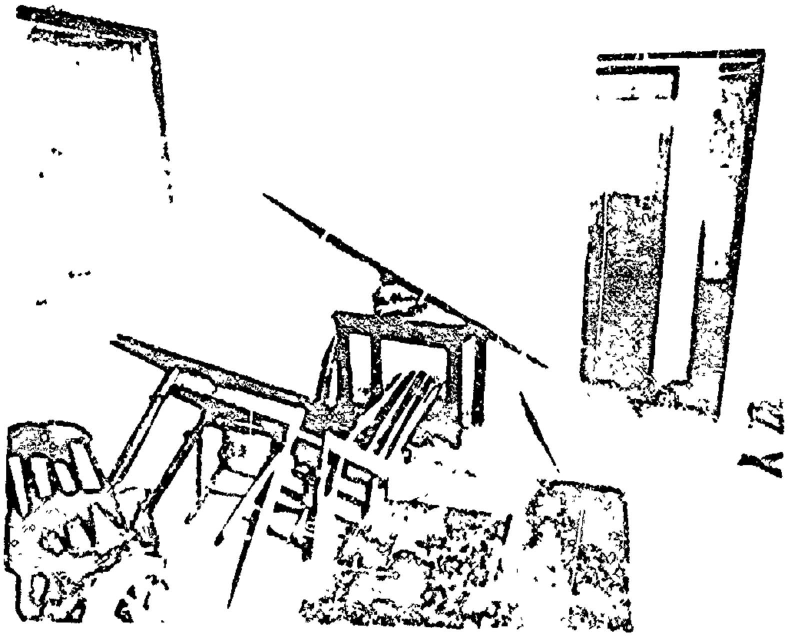


Fig. 2-7. Rear of the Kitchen, House I-1

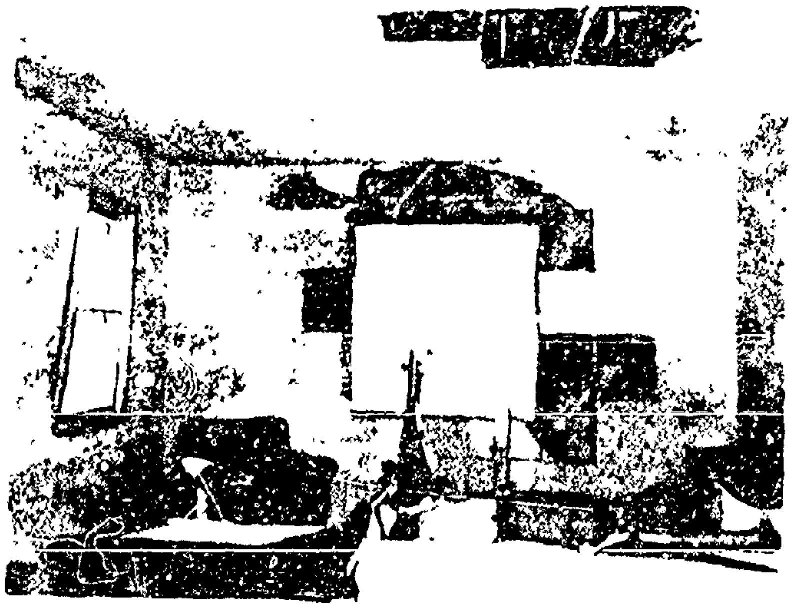


Fig. 2-8. Master Bedroom Damage, House I-1

Figure 2-9 is a view of the front roof rafters taken through the hole in the master bedroom ceiling. Only one broken roof rafter is visible. However, all roof rafters on the front of the house with the exception of one near the gable end were broken at approximately midspan (see Fig. 2-10). A photograph (Fig. 2-11) taken through a hole in the rear bedroom ceiling shows the ridge board which was carried down by the broken rafters in the front of the house, and the rear roof rafters that suffered no damage.

The house leaned toward the rear, the eave at the back overhanging the rear basement wall an estimated 1 to 2 in.

Test Results, House I-2

This house was located at 3500 ft from ground zero where the incident peak overpressure was 5 psi. Figures 2-12, 2-13, and 2-14 show the front, side, and rear of the house after the blast. The house was demolished beyond repair. Figure 2-15 shows the large area over which debris was scattered. The front half of the roof broke in the middle at approximately the mid-span of the rafters, with the lower part lifting at the eaves, pivoting about the breaks and sailing through the air, then landing on the ground at the rear of the house. See Figs. 2-16 through 2-19 for enlargements of motion picture frames taken of the test.

The chimney fell toward the rear of the house at an angle of about 45 degrees to a line to ground zero and was found lying on the ground broken into large sections. Because of the clouds of dust raised during the final collapse of the house, it is difficult to determine from the motion pictures whether the breakup of the chimney occurred before or after it reached the ground.

The first story stud walls disintegrated, allowing the second story to drop on the first floor. Most of the living room floor sagged into the basement due to broken joists. The first floor framing system moved, in general, as a unit toward the rear of the house, about 2 ft at the right side (looking at the front of the house) and 1 ft at the left. The ends of the 6- by 8-in. wood girders were pushed through the masonry foundation wall

Fig. 2-9. Master Bedroom Ceiling Damage, House I-1

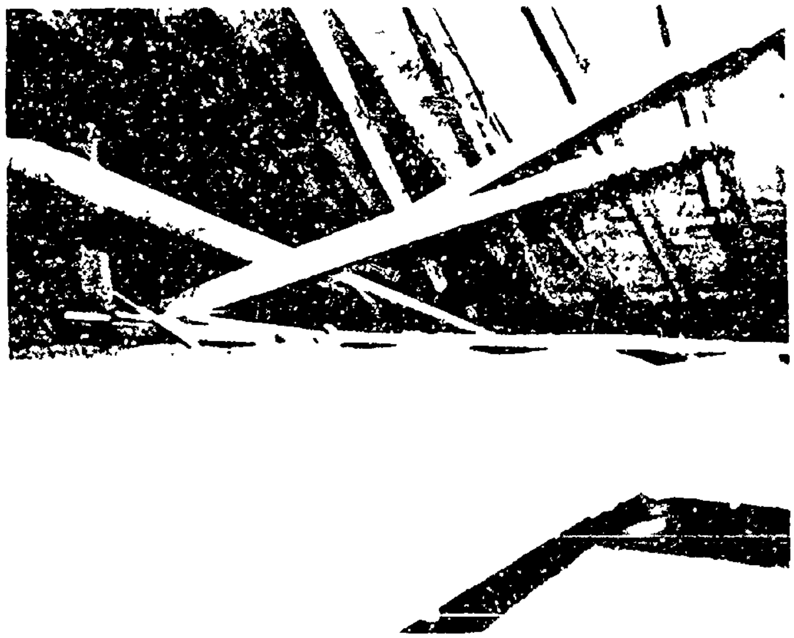


Fig. 2-10. Damage to Roof, House I-1

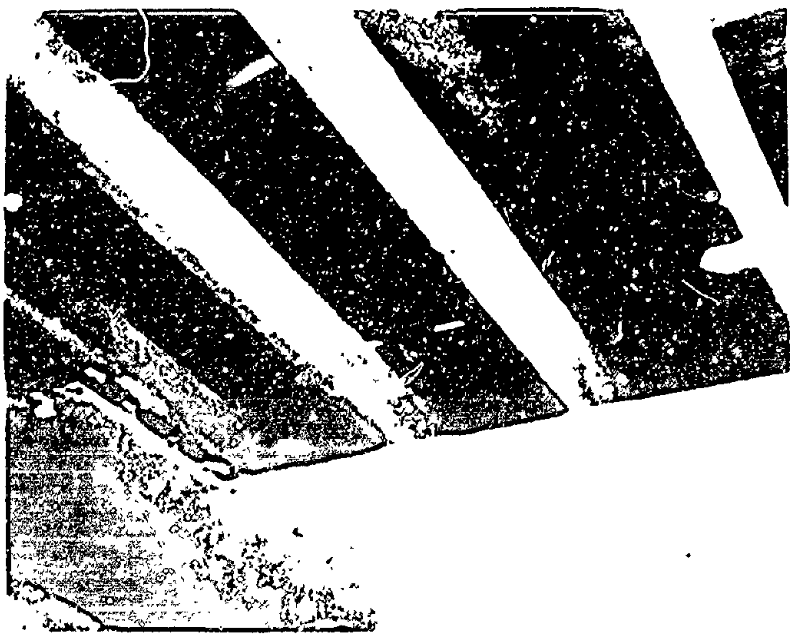


Fig. 2-11. Ridge and Roof Rafters, Rear of House I-1

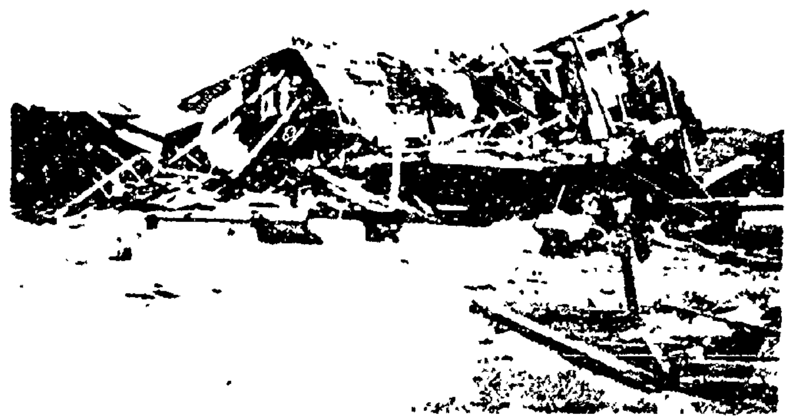


Fig. 2-12. Front of House I-2

Fig. 2-13. Side of House I-2

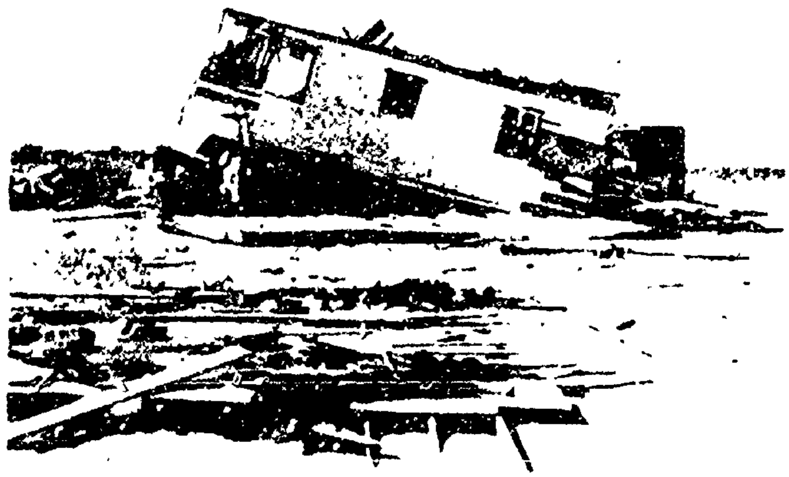


Fig. 2-14. Rear of House I-2

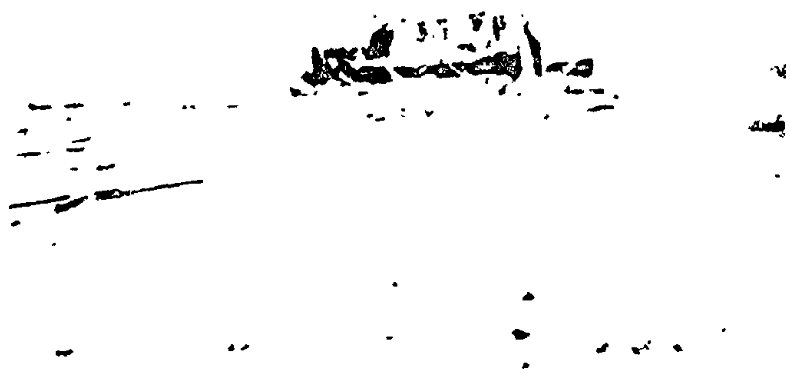


Fig. 2-15. Debris from House I-2

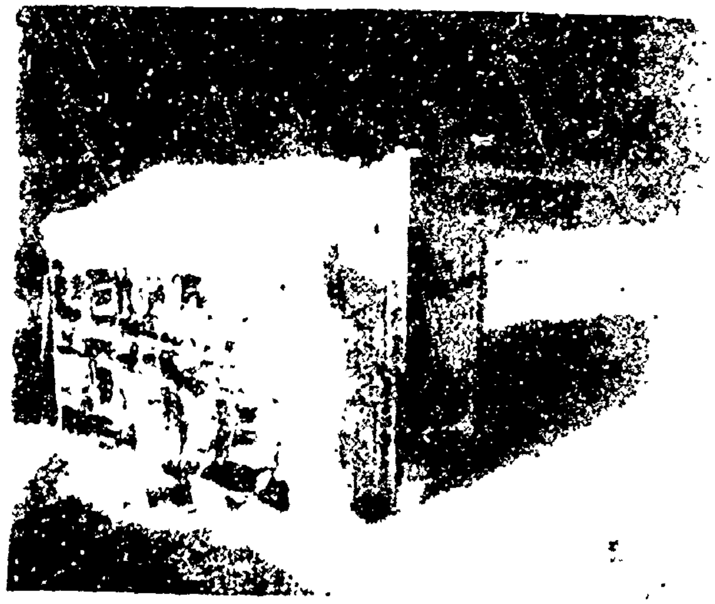


Fig. 2-16. House I-2, 1-3/4 sec After Detonation. The blast arrives. The front buckles, fragments fly from the roof, and the roof itself is ripped upward.

Fig. 2-17. House I-2, 1-22 24 sec After Detonation. The lower front wall is completely destroyed.

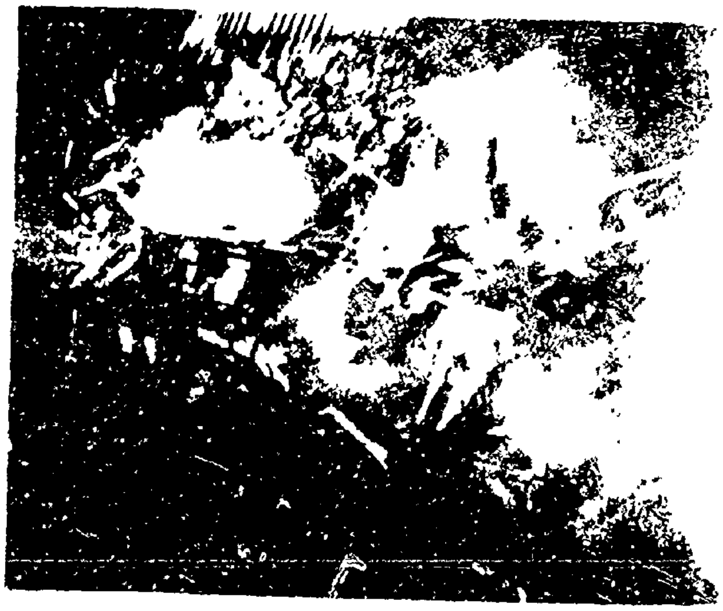


Fig. 2-18. House I-2, 2-3/24 sec After Detonation. The second story is being pushed back.

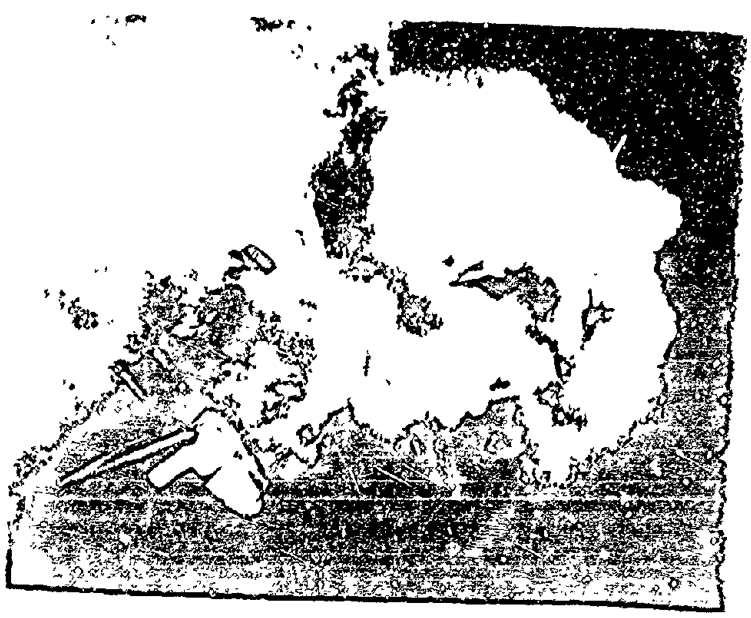


Fig. 2-19. House I-2, 2-2/3 sec After Detonation. This once was a house.

at the rear of the house. The ends of the wood girders at the front of the house moved off their bearings a maximum distance of 15 in. and the girders cantilevered from the front pair of pipe columns. Base and cap plates of the pipe columns leaned to the rear but did not overturn.

The kitchen and dining room areas were completely covered with debris from the second floor. Figure 2-20 shows the living room portion of the first floor sagging into the basement.

The second story did not drop vertically on to the first floor. The right front corner of the second floor settled 5 ft 8 in. from the front and 8 ft 3 in. from the right-side basement wall, while the left front corner of the second floor was 12 ft from the front basement wall and overhung the left-side basement wall by 10 ft 2 in. The motion appeared to be rotational and toward the left rear corner of the foundation wall.

The box-sill construction used at the top of the block foundation wall failed. Generally, the 2- by 8-in. plate, which was bolted to the block wall, remained in place. In the front of the house, the 2- by 8-in. closure or header split at the top horizontally, with the top portion moving with the first floor and the lower portion remaining with the plate. At the sides of the house, where the closure was nailed into the ends of the floor joists, the nails bent allowing the joists to slide to the rear of the house with the floor and separating the closure from the plate.

The foundation wall above grade suffered little damage on the front and sides but was damaged at the rear by the movement of the first floor system. However, the front foundation wall was cracked through vertically from sill to basement floor at each end, about 1 ft from the corner, and was moved in at the top about 1 in., hinging at the basement floor level. The hinged wall showed no bowing or cracking however. Lateral earth pressure due to the pressure on the ground in front of the house was the most probable cause of this effect.

Fig. 2-20. Living Room from Front of House I-2

Test Description, Houses I-3 and I-4

In 1955 during Operation TEAPOT, two Type I houses were exposed to the blast from a nuclear device with an approximate 30 kt yield (Apple II).* These houses were similar in size and layout to the other two-story wood houses described earlier in this section, but were redesigned to resist air blast. The only constraint on the strengthening was that it could not increase the cost of the building by more than 10 percent. The strengthening in general consisted of:

> Stronger foundation connections (4- by 8-in. sill plate with 5/8-in. bolts on 2 ft. centers, instead of a 2- by 4-in. sill plate with 1/2-in. bolts on 5-ft centers);
>
> Larger first floor joists (2- by 10-in. instead of 2- by 8- in.), solid bridging (2- by 1-in.) instead of cross-bridging (1- by 3-in.), and metal joist hangers;
>
> The second floor framing was increased in size (2- by 6-in. to 2- by 8-in.). Metal joist hangers were used, solid-bridging replaced the conventional cross-bridging in the first and last joist bays and 5/8-in.-round wrought iron framing rods were installed on 48 in. centers in these same joist bays, anchoring the joists to the exterior wall framing;
>
> The second floor ceiling joists were increased in size (2- by 6-in. to 2- by 8-in.), metal joist hangers were used and wrought iron strap hangers were installed over the center beam to the lower edge of each abutting ceiling joist to strengthen this connection;
>
> The roof rafters were increased in size (2- by 6-in. to 2- by 10-in.);
>
> The exterior walls were strengthened by the change to a "balloon" method of framing and increasing the stud size (2- by 4-in. to 2- by 6-in.).

Construction drawings of this house are presented in Fig. 2-21. The specifications were very similar to those of the Type I house described earlier except for the changes noted above, and a considerably different nailing schedule, using specially grooved nails. This nailing schedule was as follows:

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* Test data obtained from Ref. 2.

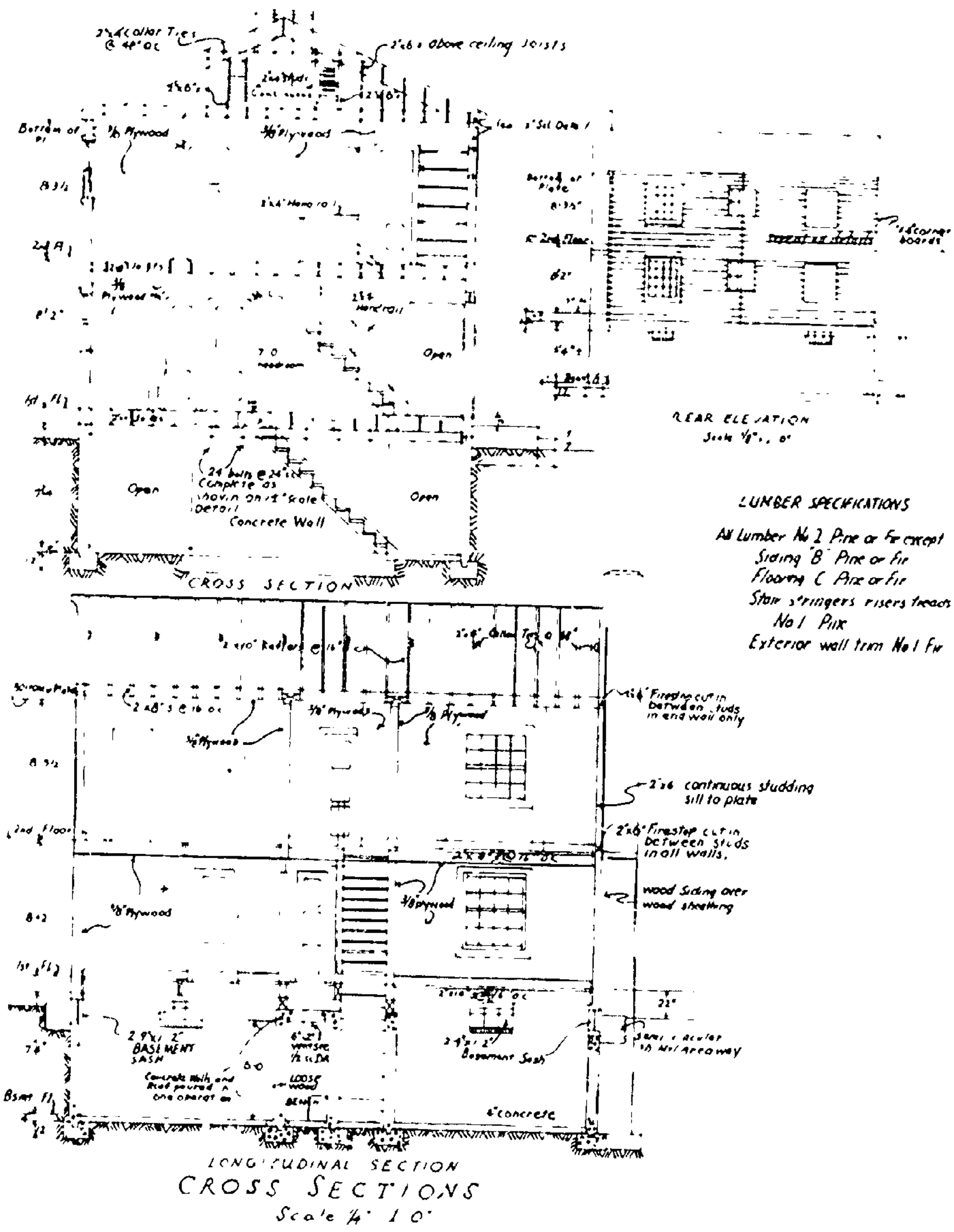


Fig. 2-21. Construction Drawing, Type I House (strengthened version)

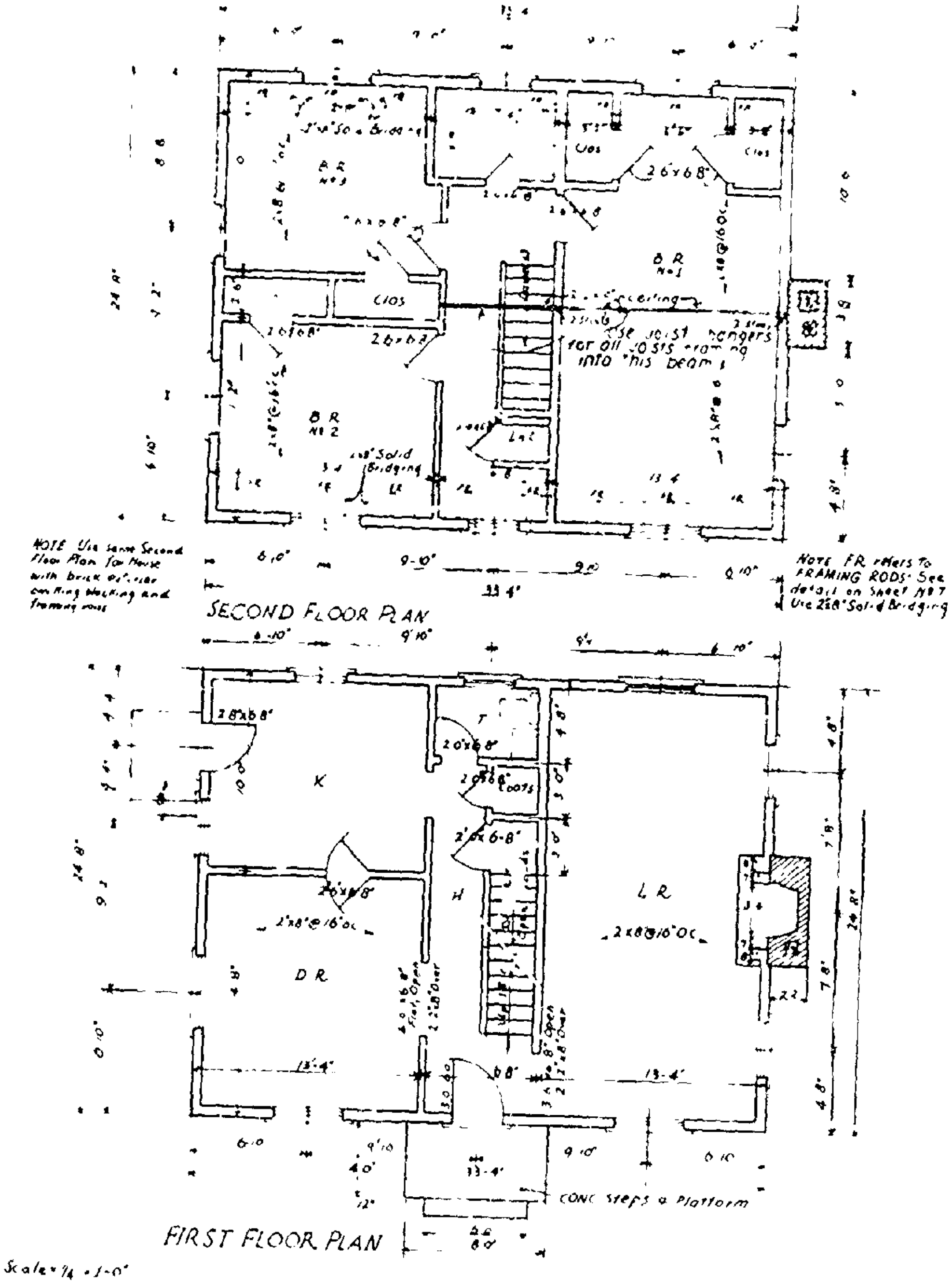

SECOND FLOOR PLAN
B.R. No 1
B.R. No 2
Clos
Use joist hangers for all joists framing into this beam
Note FR refers to FRAMING RODS. See detail on Sheet No 7 Use 2x8" Solid Bridging
FIRST FLOOR PLAN
K
D.R.
L.R.
H
CONC Steps & Platform

Fig. 2-21. (cont.)

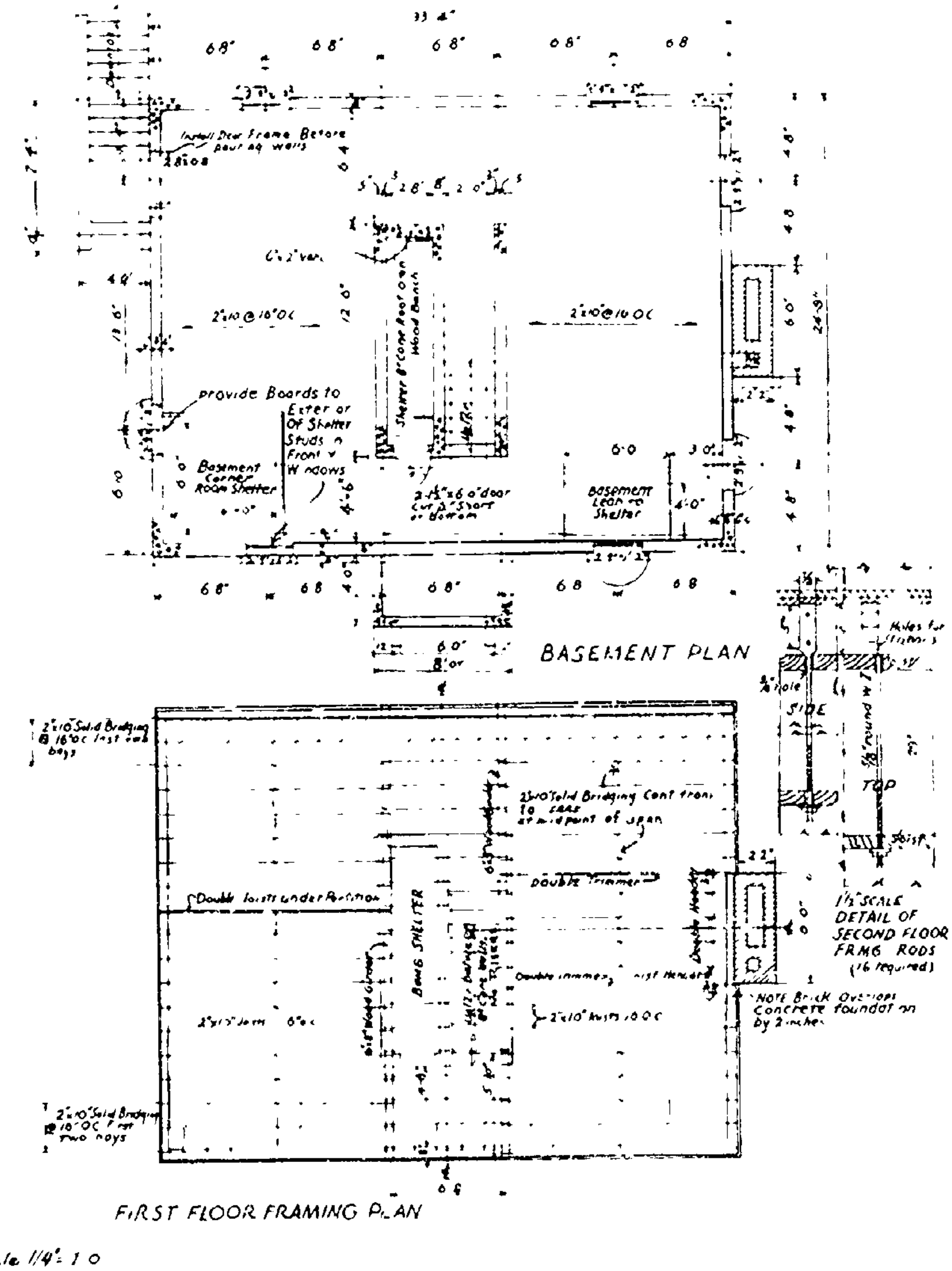

BASEMENT PLAN
provide Boards to
Basement Corner Room Shelter
Basement Lean-to Shelter
SIDE
TOP
DETAIL OF SECOND FLOOR FRMG RODS
Double Joists under Partition
Double Trimmer
FIRST FLOOR FRAMING PLAN

Fig. 2-21. (cont.)

First Floor

Joist ends to sill (toenail two each side, staggered)	4-3½ in.
1st and last joist to sill (toenail two between each stud each side of joist, staggered)	3½ in.
Joists to studs at side walls (three each side staggered)	6-3½ in.
Joists to studs at front and rear walls (from inside face nailed)	3-3½ in.
Studs to sill (toenail from each face staggered, three one face, two other face)	5-3½ in.
Corner bracer between first two joists (three each end)	6-3½ in.
Nailer to joist (toenail)	2-3½ in.
Nailer to studs (face nail)	2-3½ in.
Blocking to joists (three end nailed at each end)	6-3½ in.
3/4-in. plywood plate at sill, through filler to joists, top and bottom row, three each, middle row four; to sill four, each nail slanted in different direction	14-2½ in.
Joists to girders (toenail, each joist)	2-3½ in.
Joist to studs at center-bearing walls, three each side	6-3½ in.
Studs (2 by 4's at center-bearing wall) to girder, toenail, two one side	2-3½ in.

Second Floor

Joists to studs in all exterior walls	3-3½ in.
Joists to studs (2 by 4's at center-bearing wall) two each side	4-3½ in.
Blocking (end nail at each end)	2-3½ in.

Headers in 6-in. walls:

Nail center piece to one outside piece, on 2-ft 0-in. centers	3 in.
Nail outside piece to inside piece, on 6-in. centers	4 in.
End nail each piece to studs	2-3½ in.

Headers in 4-in. walls:	
Nail both sides on 6-in. centers	$3\frac{1}{2}$ in.
End nail each piece to studs	2-$3\frac{1}{2}$ in.
Top plates:	
Lower piece of plate to each 6-in. stud	3-$3\frac{1}{2}$ in.
Lower piece of plate to each 4-in. stud	2-$3\frac{1}{2}$ in.
Upper piece of plate to lower piece nailed from face of each piece, on 12-in. centers, staggered	3 in.
Rafters to plate on side away from ceiling joist	2-$3\frac{1}{2}$ in.
Rafters to ceiling joists, cleated three one side, two other side	5-4 in.
Ceiling joist to plate, toenail two from one side, one other side	3-$3\frac{1}{2}$ in.
Continuous closure piece:	
Into rafter slanted	3-3 in.
Into ceiling joists	3-3 in.
Into each piece of plate, staggered on 16-in. centers	3 in.
Corner posts:	
Toenail each exposed face to sill as post is assembled	2-$3\frac{1}{2}$ in.
Stud to stud on 12-in. centers, staggered	$3\frac{1}{2}$ in.
Each stud to filler block on 6-in. centers, staggered	$3\frac{1}{2}$ in.
2 by 4 nailer to stud on 16-in. centers	$3\frac{1}{2}$ in.
Joist end to joist end at laps:	
2 by 10 joists, three from one side, two from other side	5-3 in.
2 by 8 joists, two from one side, two from other side	4-3 in.
Ribbons (1 by 6 in.) into studs	2-$2\frac{1}{2}$ in.
Sheathing (1 by 8 in. or less) to each bearing	2-$2\frac{1}{2}$ in.
Exterior wood siding to each stud	3-$2\frac{1}{2}$ in.
Other joints and nailing applications, nail to provide proportionate strength	

NOTE: Wherever possible, when flat pieces are nailed, slant the nails slightly in different directions to prevent easy withdrawal.

Test Results, House I-3

This house was located 5500 ft from ground zero where the incident peak overpressure was approximately 4 psi. The superstructure of the house suffered severe damage, as can be seen in Fig. 2-22. The blast broke the rafters of the roof at midspan, and flattened the entire front section, with the sheathing and roofing attached, down against the ceiling joists. Most of the 2- by 10-in. rafters were split lengthwise. The rear half of the roof was lifted from the house and was dropped to the ground 25 ft to the rear of the house with the sheathing and most of the shingles attached.

Very few of the ceiling joists were broken; however, large sections of the plywood ceiling were blown down into the room below (see Fig. 2-23). Some of the 2- by 6-in. studs in the front wall were broken and almost all of the doors and windows were demolished. The first floor joists were split or broken. The floor was near collapse and being held up primarily by the flooring (see Fig. 2-24). There seemed to be very little damage to the second floor and first floor ceilings. As noted in Ref. 2, the house would not be suitable for occupancy without extensive and economically inadvisable major repairs.

Test Results, House I-4

This house was located 7800 ft from ground zero where the incident peak overpressure was approximately 2.6 psi. The roof was severely damaged with a number of roof rafters (on both sides) and the 1- by 12-in. ridge members being badly split. The ceiling joists suffered only minor damage, but the entire ceiling frame was badly racked and loosened. Most of the plywood in the back bedroom was blown into the room, (see Fig. 2-25) but in the front bedroom, master bedroom, and hall the ceiling was relatively intact and was lifted upward about an inch or more (see Fig. 2-26). Several of the interior doors were blown from their hinges and a few first floor joists were cracked. Very little damage was evident in the exterior and interior walls. The chimney was badly cracked but remained in place.

Fig. 2-22. Post-Shot Photos of House 1-3

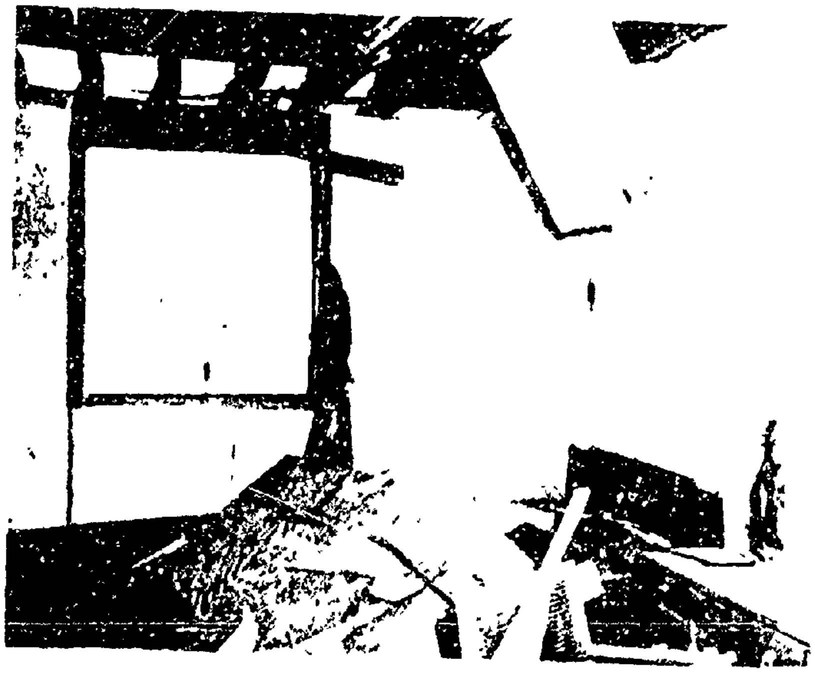


Fig. 2-23. Second Floor, House I-3

Fig. 2-24. First Floor, House I-3

Fig. 2-25. Back Bedroom Ceiling, House I-4

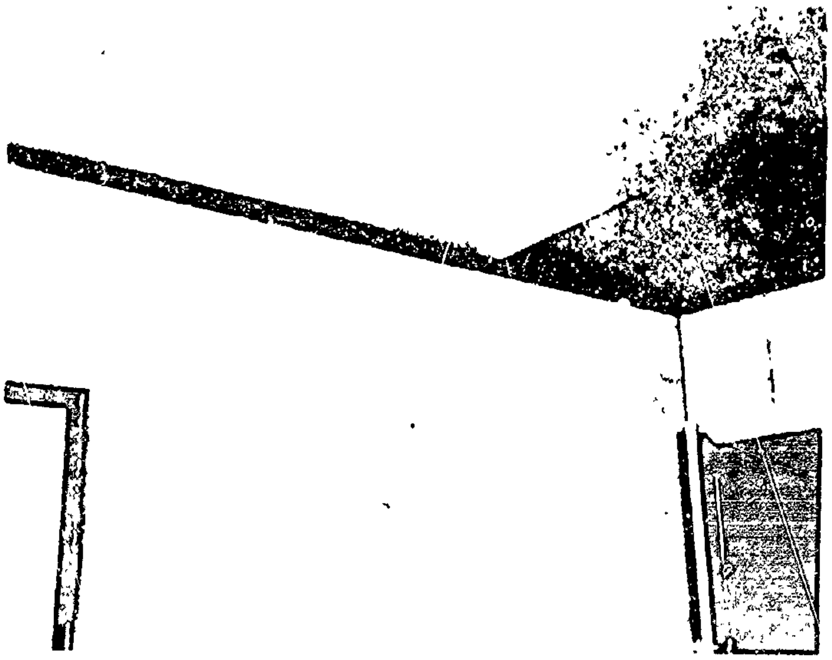


Fig. 2-26. Master Bedroom Ceiling, House I-1

Test Description, House I-5

In 1967 and 1968 two tests were conducted at the Naval Weapons Center, China Lake, California, under the sponsorship of the Department of Defense Explosives Safety Board (DODESB), to investigate the effect of "simultaneous detonation" on damage parameters at the barricaded inhabited building distance. In the first test a Type I house (no. 5) was exposed to the air blast from a 10,000 lb hemisphere of stacked TNT. (Data obtained from Ref. 3.)

Test Results, House I-5

This house was located 865 ft from ground zero where the incident peak overpressure was 1.3 psi. After the blast, all the front windows except the small one above the front door were completely removed (see Fig. 2-27). Figure 2-28 is a view of the back and left side of the house. Note the window damage on the left wall, and the fact that only one pane of glass on the back wall was broken. Moderate chimney damage is indicated by the chalk marks in Fig. 2-29. Large quantities of glass, pieces of window frame, and window shades were scattered throughout the interior of the house (see Figs. 2-30 and 2-31). Some plaster cracking was visible in several of the rooms.

Very little movement or damage to the furniture occurred and it will be noted in Fig. 2-31 that even the lampshades were not significantly moved. None of the wall-mounted mirrors were damaged.

Test Description, House I-6

After the first test the house previously discussed (I-5) was restored, as closely as possible, to a like-new condition. The two charges (5000-lb TNT cast hemispheres) were placed 865 ft from the house and detonated at approximately 20 msec intervals. The incident peak overpressure at the house was 1.2 psi. Figure 2-32 shows the front of the house after the test.

Test Results, House I-6

Although somewhat more severe, damage to the house followed a pattern similar to that seen after the first test. Damage to the windows was slightly more extensive, and a shutter at the upper-left window was torn loose, whereas no shutters were torn loose by the first test. Figure 2-33 , a photograph

Fig. 2-27. Front and Right Side of House I-5

Fig. 2-28. Back and Left Side of House I-5

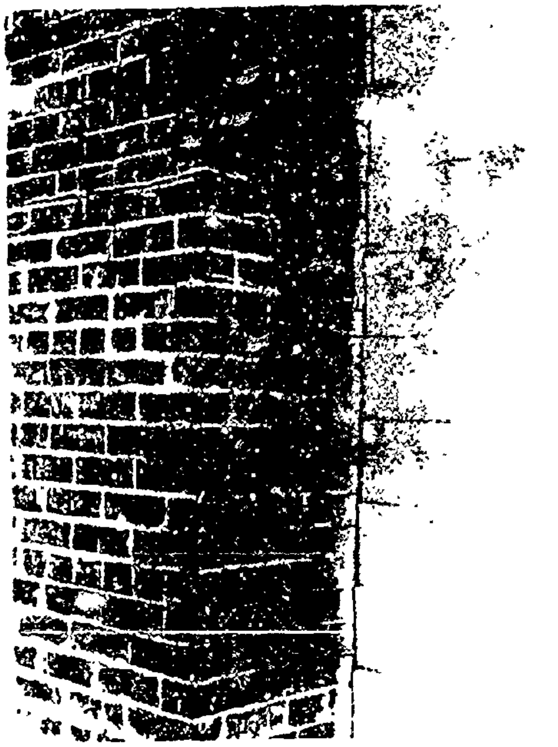


Fig. 2-29. Damage to Chimney, House I-5

Fig. 2-30. Upstairs, Front Bedroom, House I-5

Fig. 2-31. Upstairs, Master Bedroom, House I-5

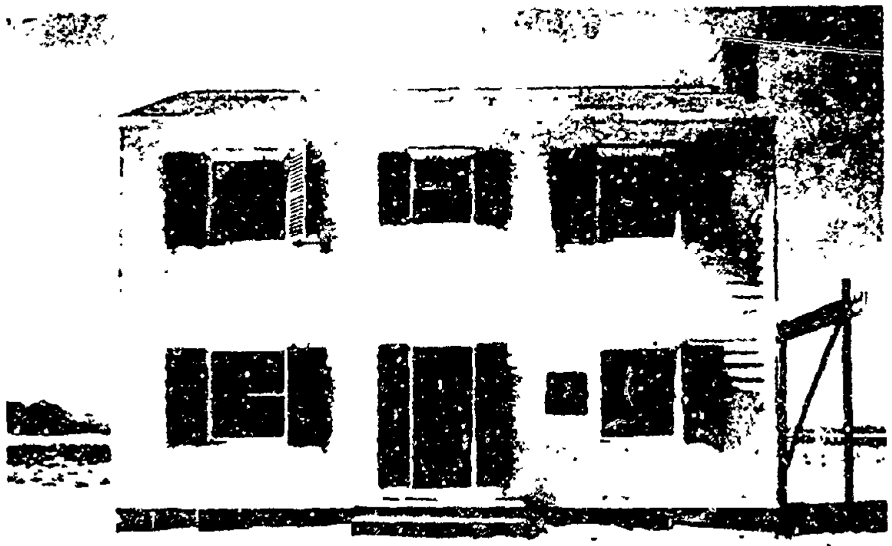


Fig. 2-32. Front Side of House I-6

Fig. 2-33. Back and Left Side of House I-6

of the same area as in Fig. 2-27, shows that window damage was substantially greater after the second test than after the first. All windows forward of the centerline of the house were damaged.

In Fig. 2-34, it may be seen that damage to the chimney was more severe after the second test than after the first. Cracks were larger and more spalling occurred; a large portion of the chimney was separated from the wall by an inch or more.

Inside the house, plaster cracking was generally more severe. The door between the dining room and kitchen was badly damaged (Fig. 2-35). Figure 2-36 shows damage to a rafter, apparently the most significant damage to a structural element in the house from either test.

Damage to the interior of the upstairs was about the same as observed in Test 1, except that much of the flying glass was intercepted by styrofoam glass traps and never reached the floor. Again, no mirrors were cracked and no furniture moved. Damage to the downstairs interior was also comparable to that from the first test, as neither flying glass and pieces of window frame nor the blast itself significantly disturbed the position of any of the furniture, including the lampshades (see Figs. 2-37 and 2-38).

Test Description, House I-7

In 1968 during Operation PRAIRIE FLAT at the Defence Research Establishment, Suffield, Alberta, Canada, House I-7 was exposed to the air blast from a 500-ton tangential sphere of stacked TNT. Data from this test was obtained from Ref. 4.

House I-7 was a standard Type I house located 4000 ft from ground zero where the incident peak overpressure was 1.1 psi.

Test Results, House I-7

Post-test photos of the outside of this house are shown in Figs. 2-39 and 2-40. Other than extensive window damage in the front and sides of the house and removal of the front door, very little exterior damage was noted. There were only minor plaster cracks noted throughout the house, except for significant shear cracks on the sides near the windows. There was extensive

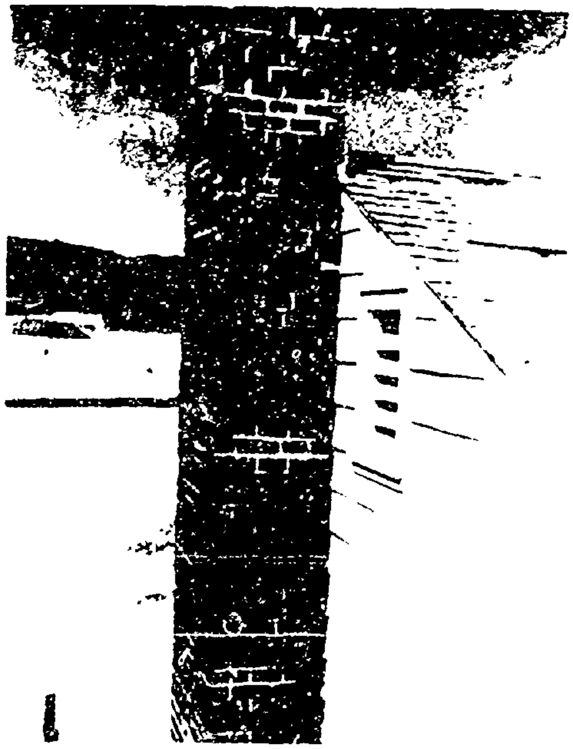


Fig. 2-34. Chimney Damage, House I-6

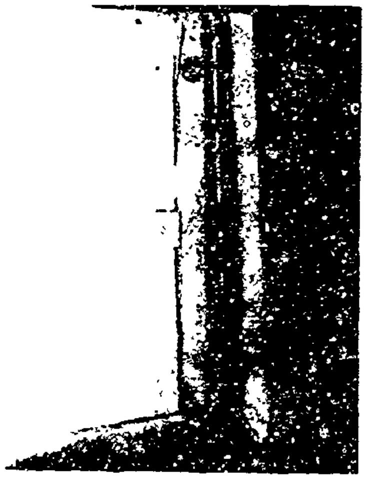


Fig. 2-35. Door Between Dining Room and Kitchen, House I-6

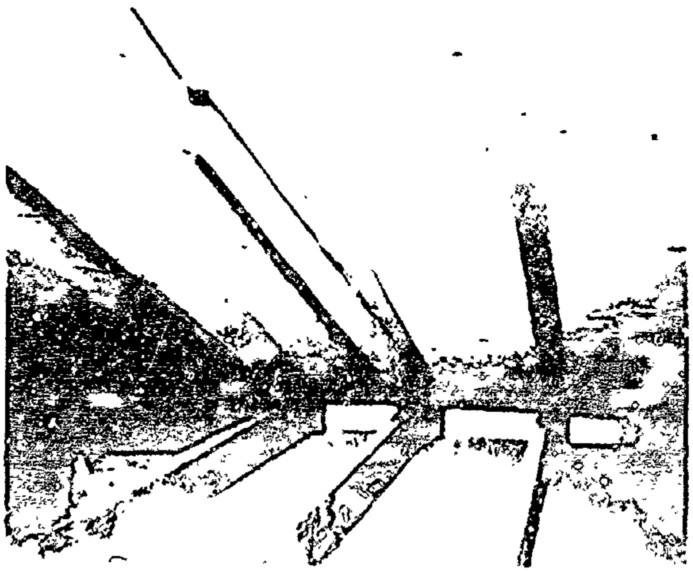


Fig. 2-36. Broken Rafter, House I-6

Fig. 2-37. Living Room, House 1-6

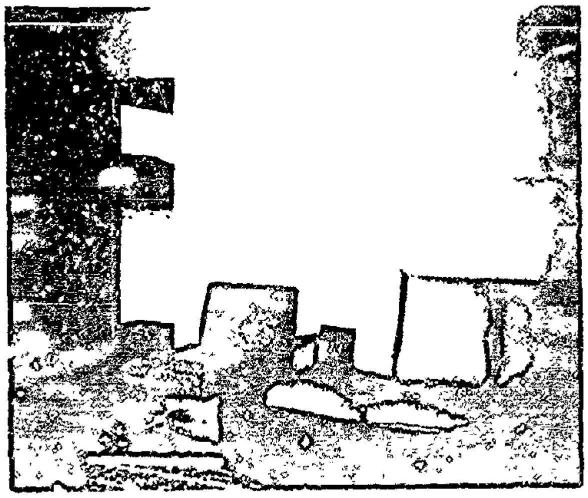


Fig. 2-38. Living Room, House 1-6

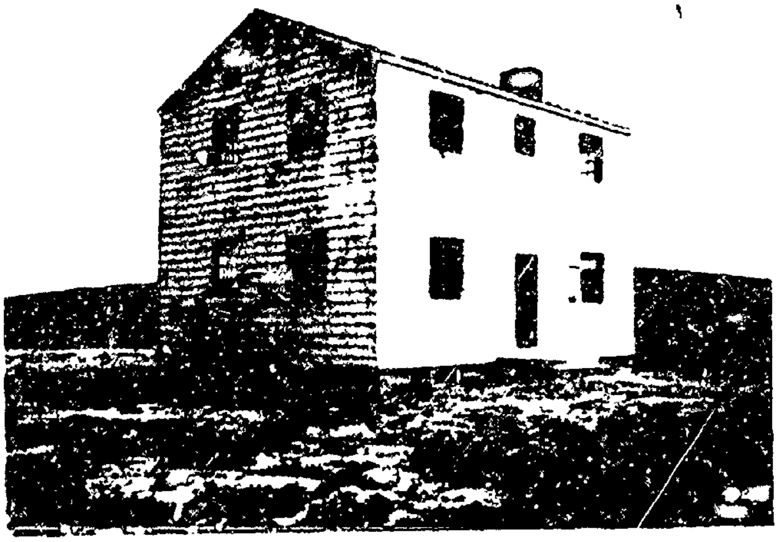


Fig. 2-39. Front and Left Side of House I-7

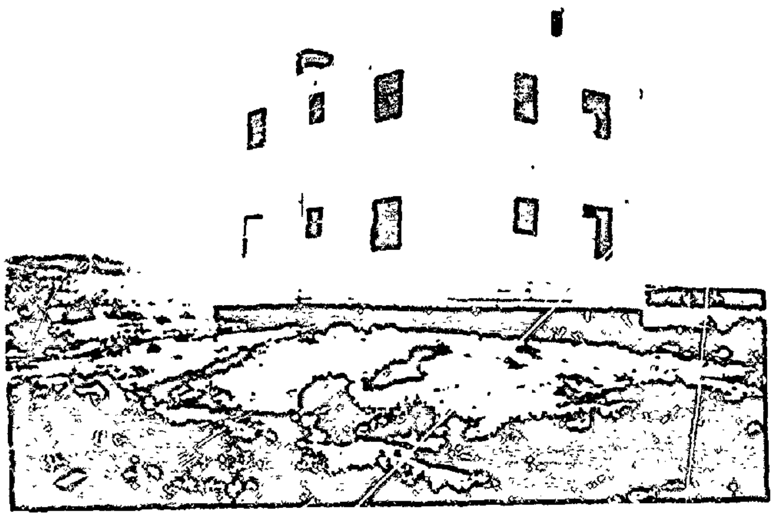


Fig. 2-40. Rear and Left Side of House I-7

ceiling plaster damage in the upstairs bathroom and rear bedroom (see Fig. 2-41). Nineteen out of 26 rafters in the front of the roof failed as well as 5 out of 9 crossties (see Fig. 2-42).

Test Description, House I-8

In 1969 a series of Ammonium Nitrate/Fuel Oil (AN/FO) tests were conducted at the Defence Research Establishment, Suffield (test data obtained from Ref. 5). During this series of tests, the house previously tested during Operation PRAIRIE FLAT (House I-7) was repaired and re-exposed to the air blast from a 100-ton hemispherical AN/FO charge. Repairs included replacement of a major portion of the roof, installation of sheetrock (replacing the damaged plaster) in the upstairs bedroom ceiling and upstairs hall, repair of damaged doors and window frames and replacement of all broken windows. Minor plaster cracks and the like were not repaired.

The house was located 1660 ft from ground zero where the incident peak overpressure was 1.6 psi.

Test Results, House I-8

Damage to the house was similar to that which occurred on House I-7 during Operation PRAIRIE FLAT, and consisted of window glass and window frame failure in the front and sides of the house and ceiling, failure in the upstairs bathroom, and rear bedroom (see Figs. 2-43 and 2-44). Nineteen out of 24 roof rafters and 5 out of 8 crossties on the front side of the roof (toward the blast) failed and two rafters and one crosstie on the back side of the roof also failed (see Fig. 2-45).

Test Description, House I-9

In the summer of 1970 the house previously tested as I-7 and I-8 was again exposed to the air blast from a 500-ton TNT charge (Event Dial Pack). (Test data obtained from Ref. 5.) Prior to this test the fireplace and chimney were removed and the house was moved from its original foundations and placed on an existing concrete pad 2256 ft from ground zero with the back of the house toward ground zero. The house axis was not exactly perpendicular to a line from ground zero, as shown in the sketch below.

Fig. 2-11. Ceiling, Rear Bedroom House I-7

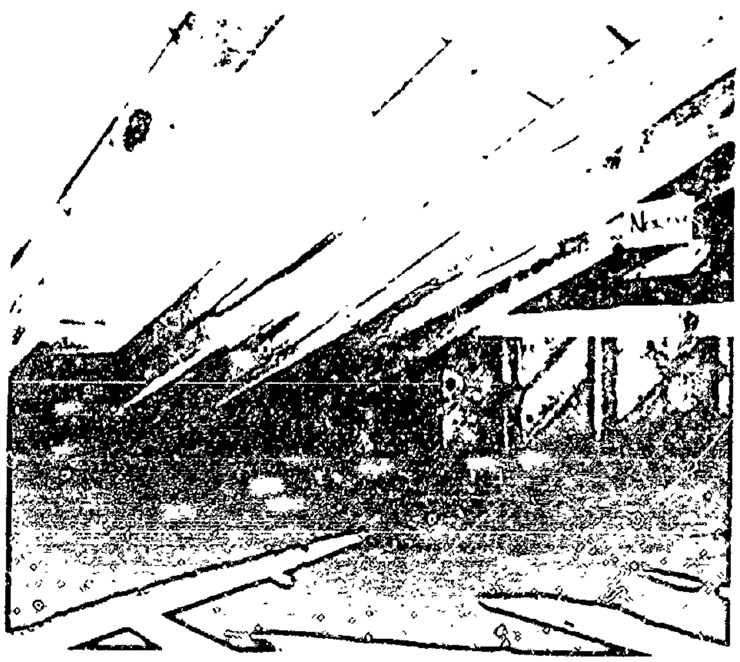


Fig 2-12. Roof Rafter Damage, House I-7

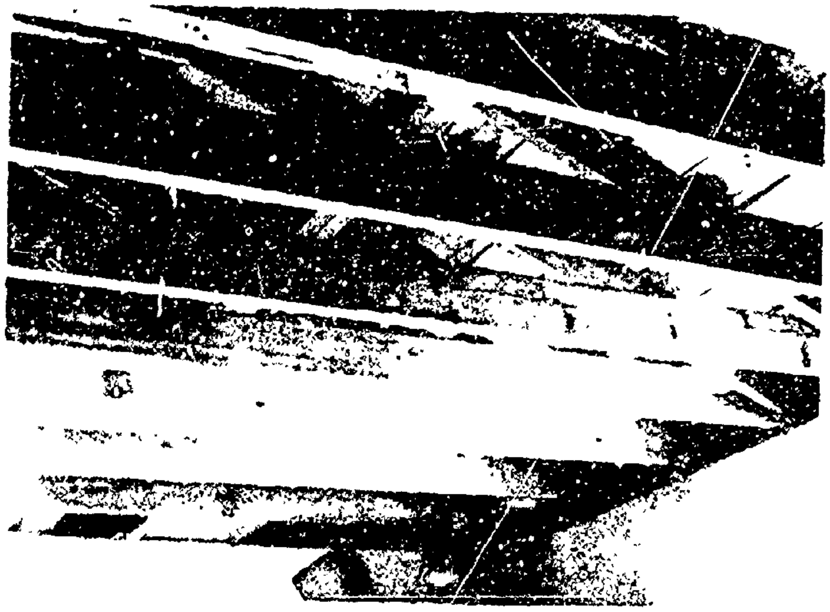


Fig. 2-13. Ceiling Damage, Upstairs Rear North Bedroom, House I-8

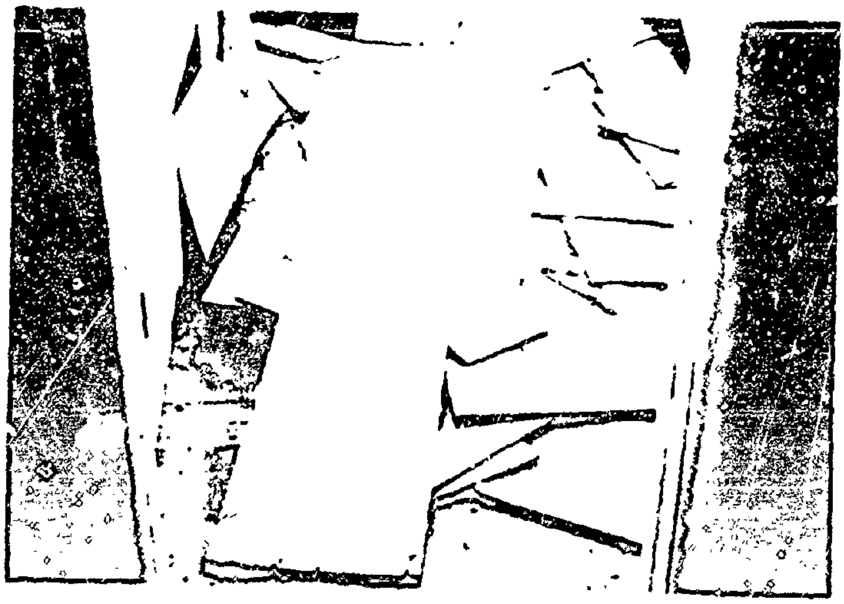


Fig. 2-11. Door and Ceiling Sheathing on Floor of Upstairs Rear North Bedroom, House I-8

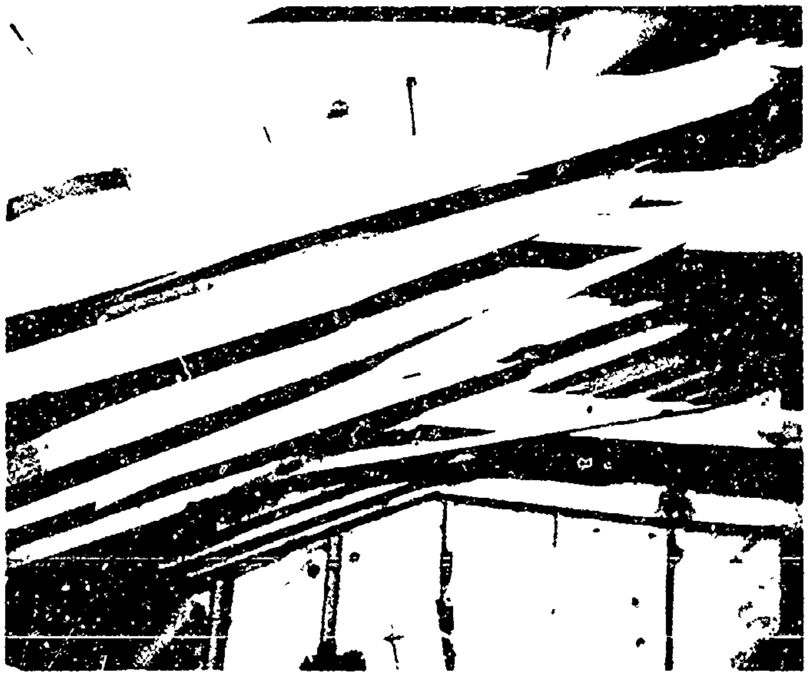
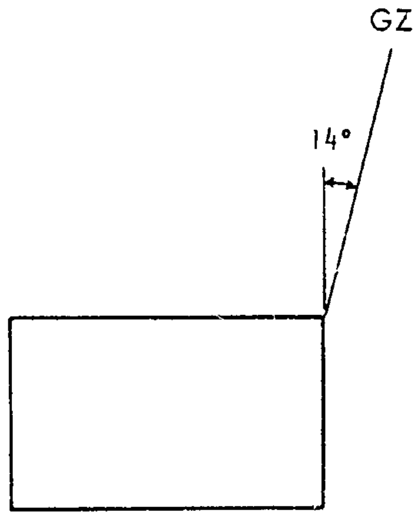


Fig. 2-45. Attic, House I-8



This house had been considerably damaged during the previous AN/FO test and sustained additional damage during removal of the fireplace and chimney and the move to the concrete pad. The majority of this damage was repaired, however. These repairs included: closing the hole left by the removal of the fireplace and chimney with new 2- by 4-in. framing, sheathing, cedar siding, and sheet rock; removing cracked and damaged plaster and broken studs and replacing them with new studs and 1/2-in. sheet rock; replacing broken window frames and windows; and repairing broken roof rafters by placing a new rafter alongside the old and nailing them together with no. 12 nails on 15 in. centers. In addition, the house was securely fastened to the concrete pad, as shown in Figs. 2-46 and 2-47.

The incident peak overpressure at this house was approximately 2.7 psi.

Test Results, House I-9

Living Room

East Wall The window in the east wall was apparently blown outward and there was moderate damage to the sheetrock. Repair would require replacement of 25 percent of the sheetrock and renailing and retaping of the entire wall.

Fig. 2-46. Method of Fastening House to Concrete Pad, East and West Sides of House I-9

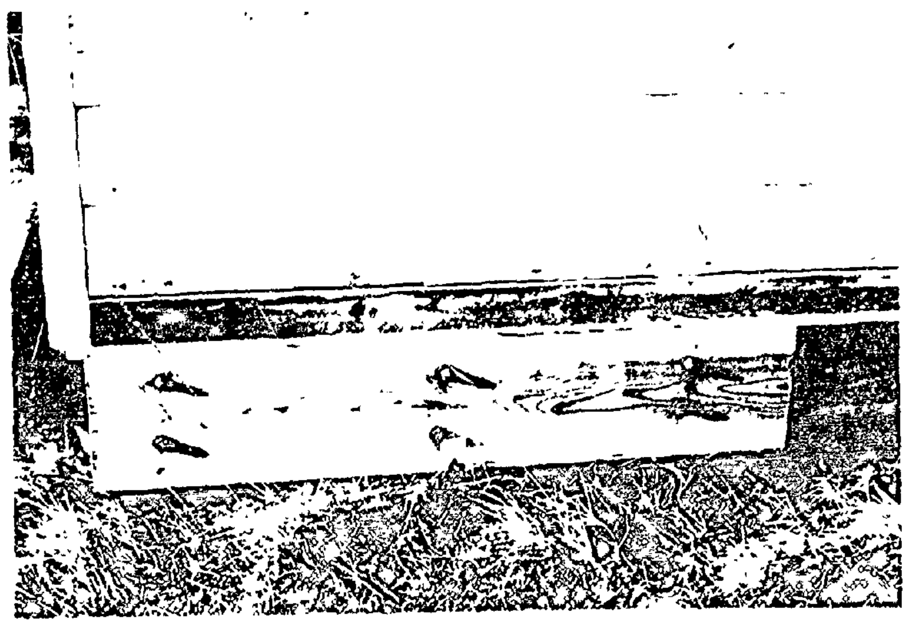


Fig. 2-47. Method of Fastening House to Concrete Pad, North and South Sides of House I-9

North Wall Both windows were blown inward. There was failure of eighteen 2- by 4-in. studs out of a total of 26, all in flexure and in the inward direction. About 40 percent of the sheetrock was blown off and repair would require complete replacement (see Figs. 2-48 and 2-49). There was an indication of shear motion in the wall, i.e., motion along the seams.

West Wall The window was blown inward and 9 out of a total of 10 studs were broken inward in flexure. Approximately 50 percent of the plaster was removed (see Fig. 2-50).

South Wall Three out of a total of 18 studs were broken and approximately 10 percent of the plaster was removed. There was extensive damage to the remainder of the wall consisting of both flexure cracks at joints and diagonal shear cracks.

Dining Room

East Wall The glass was blown inward and three studs were broken at the north side of the window and there was a 1-1/2-in. inward deformation. No sheetrock was removed; however, approximately 35 percent replacement would be required to inspect and repair the studs.

North Wall Minor shear cracking occured in the plaster, and some patching would be required.

West Wall The door between the dining room and the kitchen was blown inward off its hinges and came to rest in the doorway (see Fig. 2-51). Several flexural cracks were noted and removal and replacement of approximately 25 percent of the plaster would be required to fix the damaged door casing, etc.

South Wall The glass was blown inward and 7 out of a total of 10 studs were broken inward in flexure. Approximately 20 percent of the plaster was broken inward (flexure) and considerable shear deformations were noted. Repair would require 100 percent replacement.

Ceiling Only minor damage consisting of small cracks was noted.

Fig. 2-18. Living Room, North Wall Looking East, House I-9

Fig. 2-19. Living Room, North Wall Looking West, House I-9

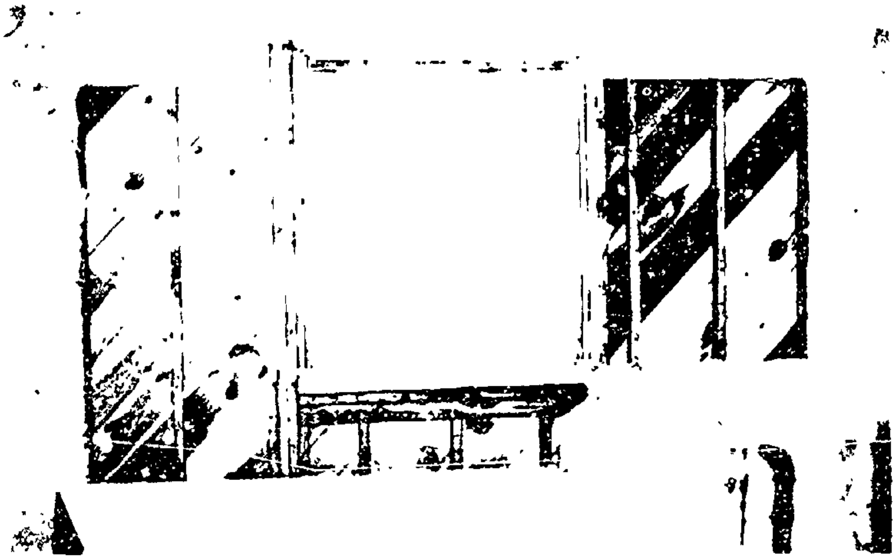


Fig. 2-50. Living Room West Wall, House I-9

Fig. 2-51. Dining Room West Wall, House I-9

Kitchen

West Wall Heavily damaged with a window blown in, 90 percent of the sheetrock removed, and 6 out of 7 studs broken (see Fig. 2-52).

North Wall Numerous shear cracks were noted and there was crushing of the plaster at the intersection of the west and north walls. Approximately 25 percent reconstruction of the wall would be required.

East Wall The damage to this wall was similar to that noted for the west wall of the dining room.

South Wall The window was blown inward. Four out of a total of 9 studs failed in flexure. Twenty-five percent of the plaster was blown inward and the remainder showed considerable evidence of shear failure. As a result, the entire wall would need to be replaced.

Ceiling The only damage noted was minor plaster cracking.

Entry Hall and Bathroom

West Wall of Bathroom The window and frame were blown into the bathroom. One stud on the north side of the window was broken inward in flexure and 25 percent of the plaster was blown inward.

East Wall of Bathroom The door was blown out and landed near the front door. Only minor plaster damage (i.e., cracks) was noted.

Entry Hall The front door was blown into the house and both closet doors were damaged (see Fig. 2-53).

Master Bedroom

North Wall The window was blown inward. Twelve out of a total of 21 studs were broken inward in flexure. All sheetrock was damaged severely and 75 percent was blown inward (see Fig. 2-54). There was also evidence of shear deformation in the remaining sheetrock.

East Wall The plate glass window was not broken; it was the only window remaining in the house. However, this particular location was protected by a glass trap. Very minor damage to the sheetrock was evident.

Fig. 2-52. Kitchen West Wall, House I-9

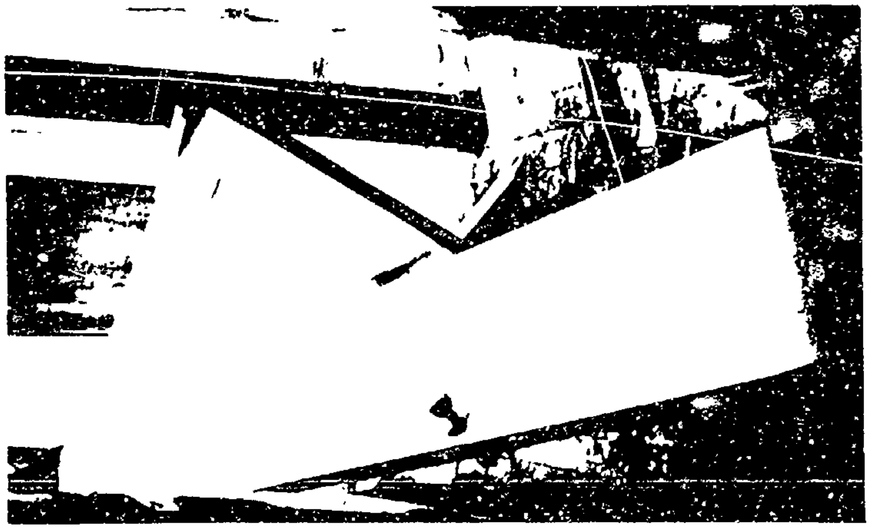


Fig. 2-53. Entry Hall Looking East, House I-9

Fig. 2-54. Master Bedroom North Wall, House I-9

South Wall The door was left open and was undamaged. No studs were damaged. Minor crack damage in the plaster was noted and there was little evidence of shear deformation.

West Wall The window was blown inward. The only stud damage noted was the splitting of a short stud under the north corner of the window. The plaster was generally loose and would require complete replacement.

Ceiling The entire plaster ceiling was blown into the room. Major pieces ranged from 16- by 48-in. to 48- by 72-in. The ceiling was constructed of 16- by 48- by 3/8-in. plaster board with expanded metal strips at the edges and at 4-ft intervals. The covering was 3/8-in. plaster. No ceiling joist damage was noted (see Fig. 2-55).

Northwest Closet The closet door, which was closed prior to the test, was almost removed from its hinges and the jamb was severely damaged. One out of 3 studs was broken in both the north and west walls of the closet. There was complete destruction of the plaster on the north wall with 80 percent removed by the blast; extensive damage to the plaster on the west wall was noted. The entire ceiling was blown into the closet. Repair would require complete replastering of the north and west walls and ceiling.

Southwest Closet The south wall showed evidence of shear deformation and the entire ceiling was blown downward.

Second Bedroom

North Wall The door, which was closed prior to the blast, was blown off its hinges and into the room. The only other damage noted was minor plaster cracking with some evidence of shear deformation.

East Wall The window was blown inward and a large quantity of glass was embedded in the glass trap. Out of a total of 7 studs, only those 2 adjacent to the window were damaged. About 25 percent of the plaster board was damaged; however, 50 percent replacement would be required to repair the studs.

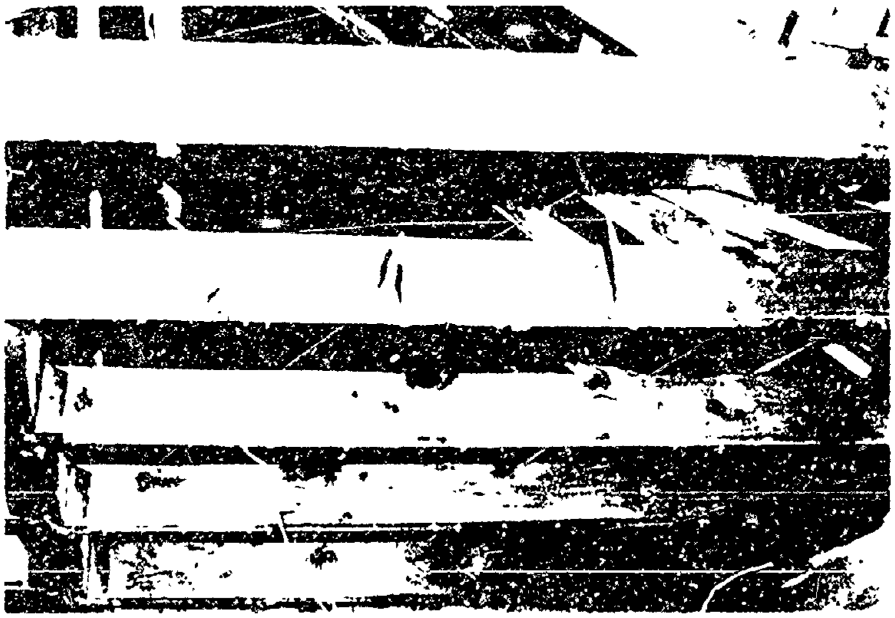


Fig. 2-55. Ceiling of Master Bedroom, House I-9

South Wall The window was blown inward. Of the 7 studs in this wall, 2 multiple studs adjacent to the windows were broken. Significant plaster damage (40 percent) in both flexure and shear was noted. This would probably require 75 percent replacement to repair both plaster and studs.

West Wall No visible damage was inflicted by the test.

Ceiling The entire ceiling (plaster) was broken into the room without failure of any ceiling joists. The pieces of debris were mostly 16- by 48-in. which is the underlaying plasterboard size.

Closet The entire ceiling was blown into the closet, but no other damage was detected.

Third Bedroom

North Wall Considerable plaster damage was noted, including local crushing at the intersection of the north and west walls and some shear cracking. The total plaster damage would require about 40 percent replacement.

West Wall The window was blown inward and 5 of the 7 studs were broken in flexure. Most (75 percent) of the plaster was blown into the room, and repair would require complete replastering.

South Wall The window was blown into the room. Four out of 10 studs were broken in flexure. The plaster showed both flexure and shear failure and would require about 75 percent replacement (see Fig. 2-56).

East Wall The closet door was blown into the closet. No apparent stud damage was noted and only minor plaster cracking was found.

Ceiling The ceiling was completely blown into the room. Again, no damage was sustained by the ceiling joists. The major sheetrock pieces were:

two 4-ft by 8-ft sheets
two 4-ft by 5-ft sheets
three 3-ft by 4-ft sheets

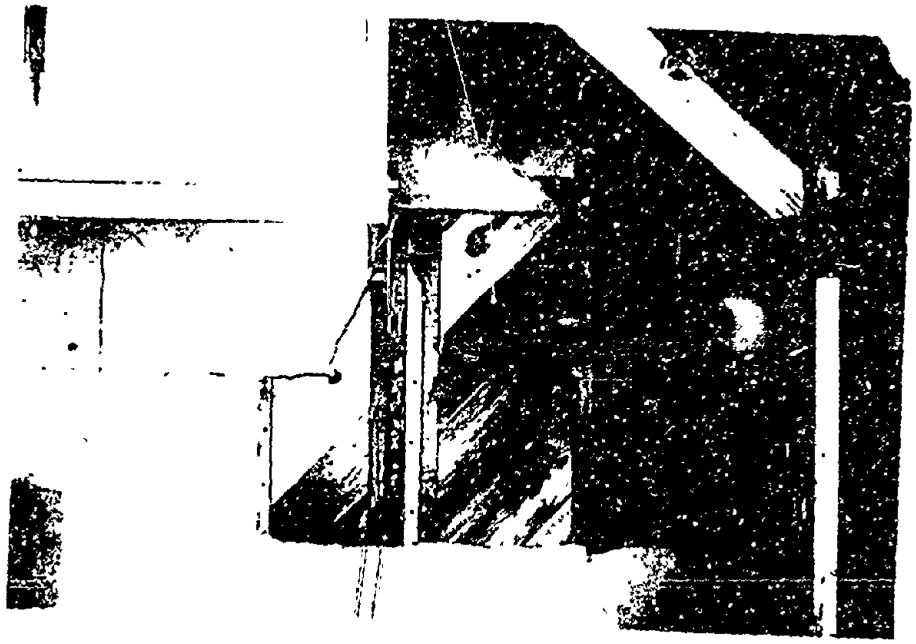


Fig. 2-56. South Wall of Rear Bedroom, House I-9

These were basically the pieces put up during repair. The closet ceiling was blown into the closet.

Second Floor Hall and Bathroom

Bathroom Area The window on the west wall was blown inward and the door on the east wall was blown outward (easterly) and almost removed from its frame. The studs on both sides of the window and the door failed in flexure. Although the plaster on the east wall and west wall was only moderately damaged (50 percent), repair would probably require the replastering of all walls.

Ceiling The hall and bathroom ceiling of the house were not removed, but were severely damaged. It is interesting to note that, as in previous tests, the leeward (easterly) portion of the ceiling was more severely damaged than the blastward portion. This type of damage predominated in the entire upstairs. Repairs would require the replacement of the entire ceiling on the second floor.

Roof System and Loft

All rafters on the blastward side were broken in flexure. Also, all the blastward rafters were pulled loose from the ridge, apparently in tension rather than in shear. No failure was detected in any of the leeward rafters (see Figs. 2-57 and 2-58).

All (9) 2- by 4-in. crossties were removed during the failure. All rafter to tie joints failed in shear, and 4 of the ties were broken in flexure.

A few breaks are seen in the blastward sheathing, but they appear to have occurred after the rafter failure, i.e., as a result of excessive roof deformations.

House Exterior

East Wall Some siding damage was noted at the corner of each window (see Fig. 2-59).

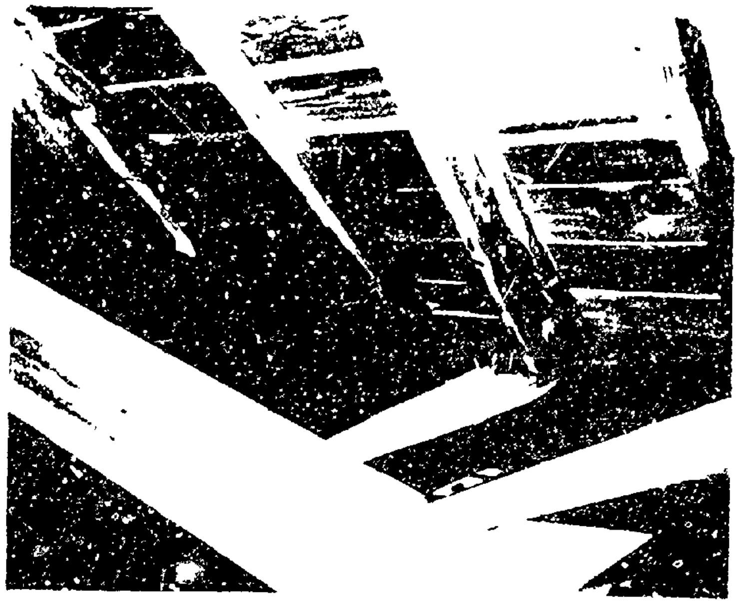


Fig. 2-57. Roof Damage, Blastward Side of House 1-9

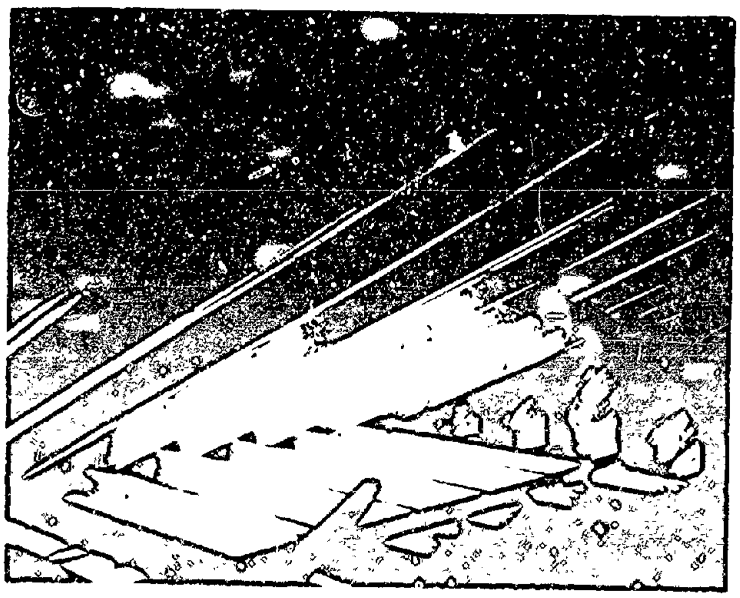


Fig. 2-58. Roof Damage, Leeward Side of House 1-9

Fig. 2-59. House Exterior, East and South Side of House I-9

North Wall Some differential motion normal to the plane of the wall at a splice was observed. This was caused by the lack of continuity in the sheathing at the fireplace patch. Continuity of the sheathing would have little effect on the extent of wall failure as the studs on both sides of the splice failed.

West Wall Considerable siding damage was observed under each window in the region of stud failure (see Fig. 2-60).

South Wall Relatively insignificant siding damage was observed under each window.

Test Description, Houses I-10 and I-11

In March and April 1959 two full-scale tests simulating an accidental detonation of Nike-Hercules missiles in an underground storage magazine were conducted at the White Sands Missile Test Range in New Mexico. (Data obtained from Ref. 6.) During these tests 8 Type I houses were exposed to the air blast from three missile detonations. Four houses were exposed to a peak incident overpressure of 1.1 psi from a charge estimated to be 2550 lb, and four houses to a peak incident overpressure of 1.27 psi from a charge estimated to weigh 3500 lb. The house damage information for these tests was obtained from Ref. 4. The data presented there was not sufficient to determine the damage to each house, but was adequate to describe the most severely damaged house in each test. These houses are identified as nos. I-10 for the 2550 lb test and no. I-11 for the test with 3500 lb of TNT

Test Results, House I-10

The estimated peak overpressure experienced by this house, which was located 528 ft from an estimated 2550 lb of TNT, was 1.1 psi. Damage to the main structure members of the house was minor, with damage being limited to 7 broken rafters in the front roof. The breaks, in general, occurred where knots were located on the tension side, near the central portions of the members.

Moderate plaster damage was evident across the ceiling of the master bedroom under the built-up beams. The front door, all of the front windows, most of the side windows, and very few of the rear windows were removed. The

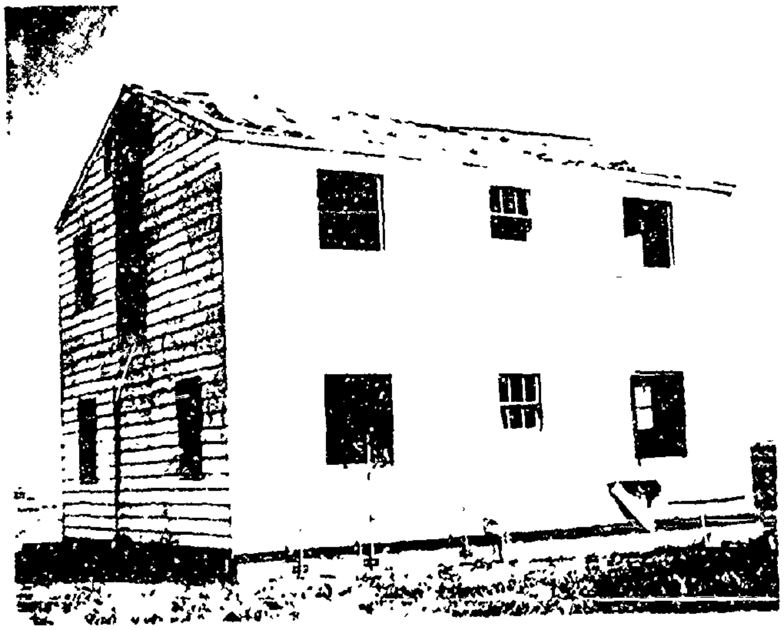


Fig. 2-60. House Exterior, North and West Sides of House I-9

swinging door between the dining room and kitchen was also removed, and there was some superficial damage to the interior doors at the rear of the center hallway. This consisted of cracking of the door casings at the latches.

Test Results, House I-11

The estimated peak overpressure experienced by this house was 1.3 psi. This house was also located 528 ft from an estimated 3500 lb of TNT.

Structural damage from this test was much greater than that experienced by house I-10. There were 12 broken rafters in the front side of the house, and 4 joists were broken in the first floor framing, 3 each under the dining room and 1 under the living room. There were 6 broken wall studs.

Plaster damage was also much greater, with most of the cracks outlining the plasterboards. There was major ceiling damage to the rear bedroom and under the built-up beams in the master bedroom. Considerable plaster damage was found over the living room doorway. The front and interior swinging doors were blown off their hinges and in all cases, the door casings were damaged. All of the front windows, most of the side windows, and a few of the rear windows were broken. There was also major plaster damage in the front walls of the living room, dining room, and the front and master bedrooms.

Section 3
TYPE II HOUSE TESTS

INTRODUCTION

The typical Type II house is a conventional center hall, two-story, house with 8-in. load bearing masonry walls, consisting of an outer wythe of brick and a backup wythe of cinder block. The house is 33 ft 4 in. long by 24 ft 8 in. wide with a full basement and a gabled roof (see Fig. 3-1). There were four rooms on each floor and a brick fireplace in the living room. As in the case of the Type I house the walls were plastered, and the finish coat and plumbing, heating, and electrical systems were omitted to reduce the cost.

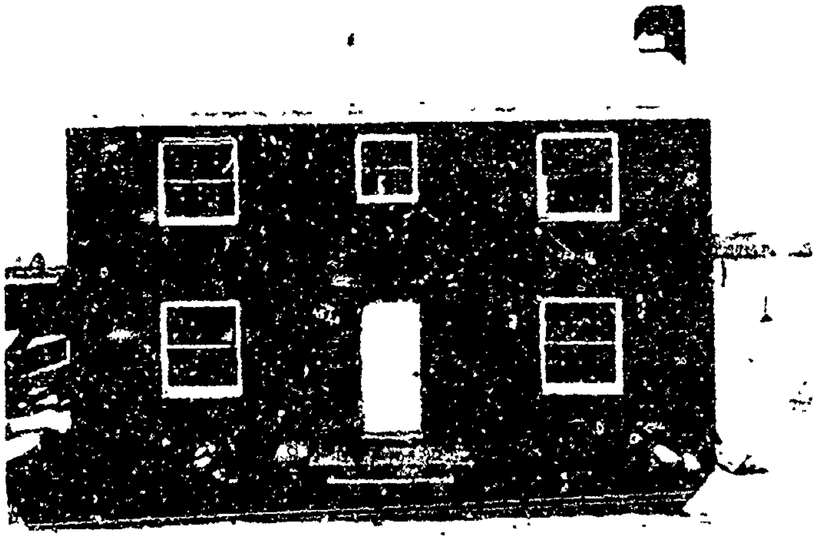
CONSTRUCTION DETAILS

Constructions drawings for the Type II house are presented in Figs. 3-2 and 3-3. The construction specifications were the same as those for the Type I house. The basement foundation walls were 12-in. concrete block. The 2- by 8-in. first floor joists had square-cut ends bearing on the inner 4 in. of the basement foundation wall. The 2- by 8-in. second floor joists had an angular fire-cut end with 4-in. bearing on the concrete-block wythe, the gable roof was of typical wood frame construction, with 2- by 6-in. rafters, 2- by 6-in. ceiling joists, and 2- by 6-in. rafter ties every third rafter.

TEST DESCRIPTIONS AND RESULTS

Test Description, Houses II-1 and II-2

The data from six Type II house tests are included in this report Two of the houses (Nos. II-1 and II-2) were exposed to the air blast from the 30 KT (Apple II) nuclear device during Operation TEAPOT. The data from these tests was obtained from Ref. 2. The remaining four houses (Nos. II-3 through II-6) were exposed to the air blast from relatively small quantities of TNT during tests at the White Sands Missile Range (Ref. 6).



Front View

Left Side

Fig. 3-1. Photographs of Type II House

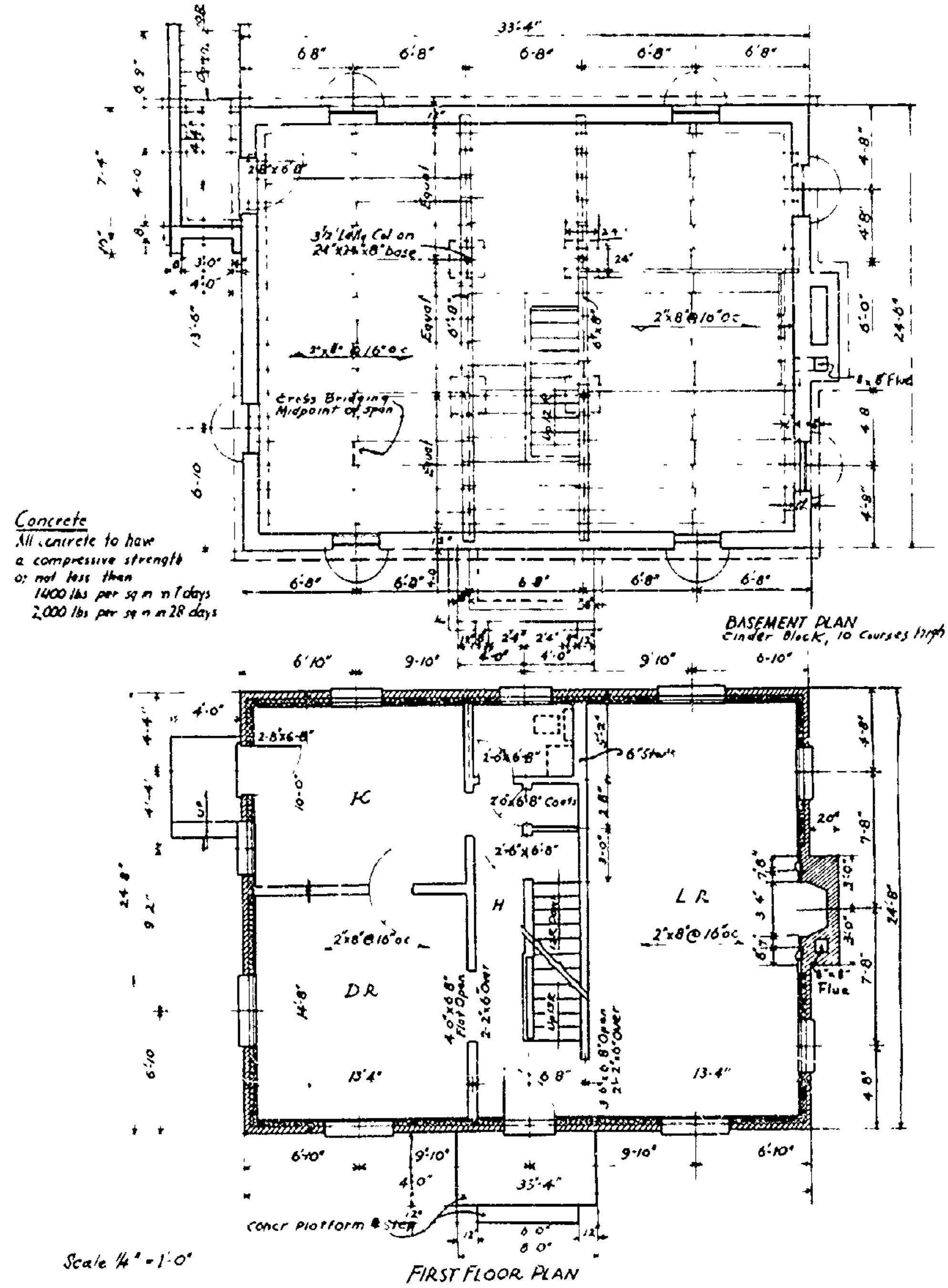


Fig. 3-2. Type II House, First Floor and Basement

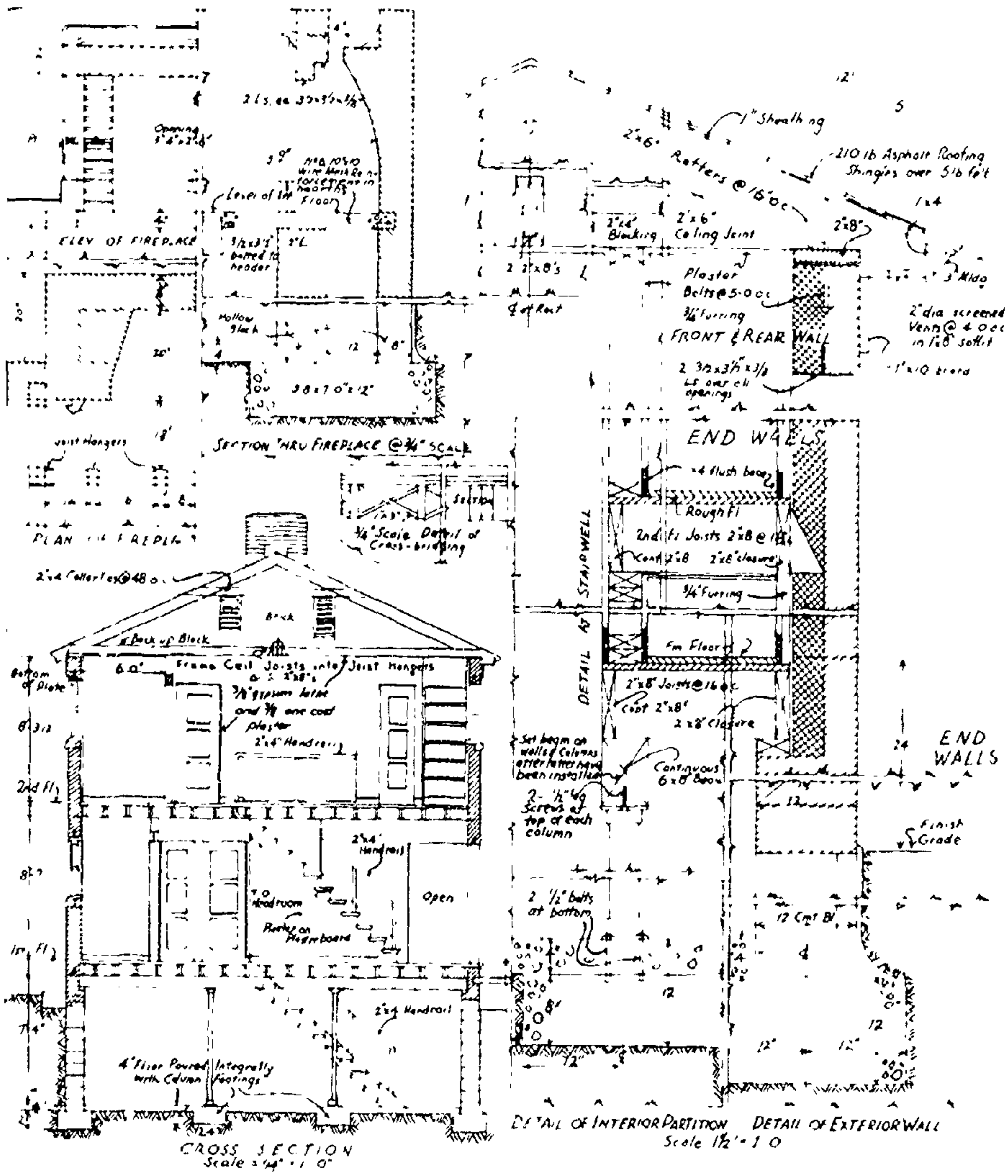


Fig. 3-3. Type II House, Sections and Detail

Test Results, House II-1

This house was located 10,500 ft from ground zero where the incident peak overpressure was 1.9 psi. There was no apparent damage to the masonry of this house (see Fig. 3-4). However, there was considerable damage to the roof and second floor ceiling framing (see Fig. 3-5). The connections of the rear rafters to the ridge failed, and the rafters dropped 4 to 6 in. below the ridge. The ridge split in the center portion, and some of the 2- by 4-in. collar beams broke in half. The ceiling joists over the rear bedroom split at midspan, and the lath and plaster ceiling was blown down into the room. The second floor framing suffered little or no damage. A few first floor joists were fractured (see Fig. 3-6). The glass in the front and side windows was blown in, and the glass in the rear windows suffered some damage. The exterior doors were blown in and demolished, and several interior bedroom and closet doors were blown off their hinges. The stair rail was broken, and the interior plastered wall and ceiling finish were badly damaged.

Test Results, House II-2

This house was located 4700 ft from ground zero where the incident peak overpressure was 5 psi. The aboveground portion of the house was demolished beyond repair (see Fig. 3-7). The exterior brick and cinder-block walls exploded outward into the yard around the house, with very little masonry debris falling on the floor framing. The chimney fell to the side of the house and lay on the ground broken into large sections. The roof was demolished and blown off; the rear side of the roof was lifted off and deposited on the ground on the far side of the house about 50 ft to the rear. Some of the bearing partitions, those around the staircase and first floor hall and those on the second floor, remained standing but were badly racked. The stair from first to second floor remained standing. The second floor partially collapsed on the first floor but on one side of the house about 50 percent of the ceiling joists remained hanging from the partition. Many of the joists did not split, and part of the second floor construction

Fig. 3-4. Post-Test Photo, House II-1

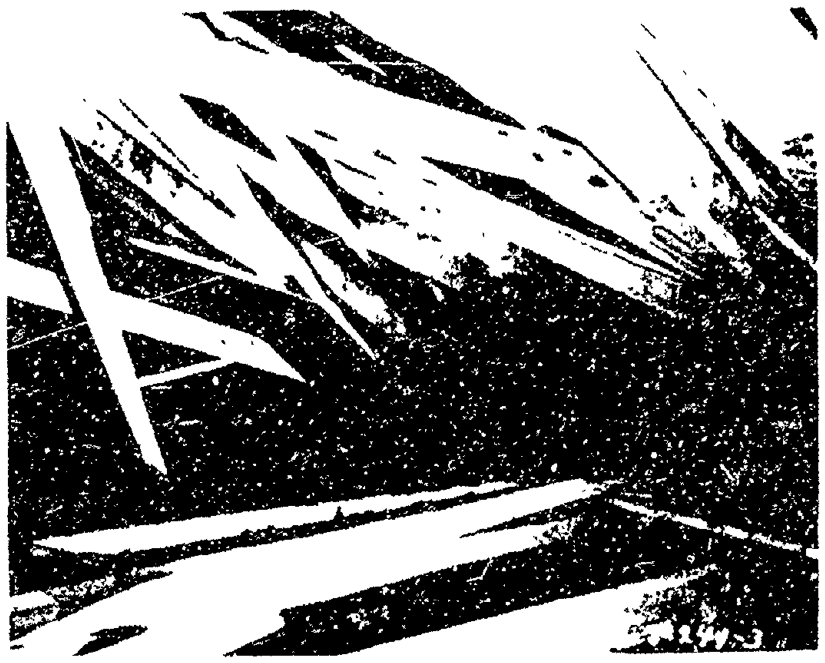


Fig. 3-5. Splintered Rafters on Front Slope of Roof, House II-1

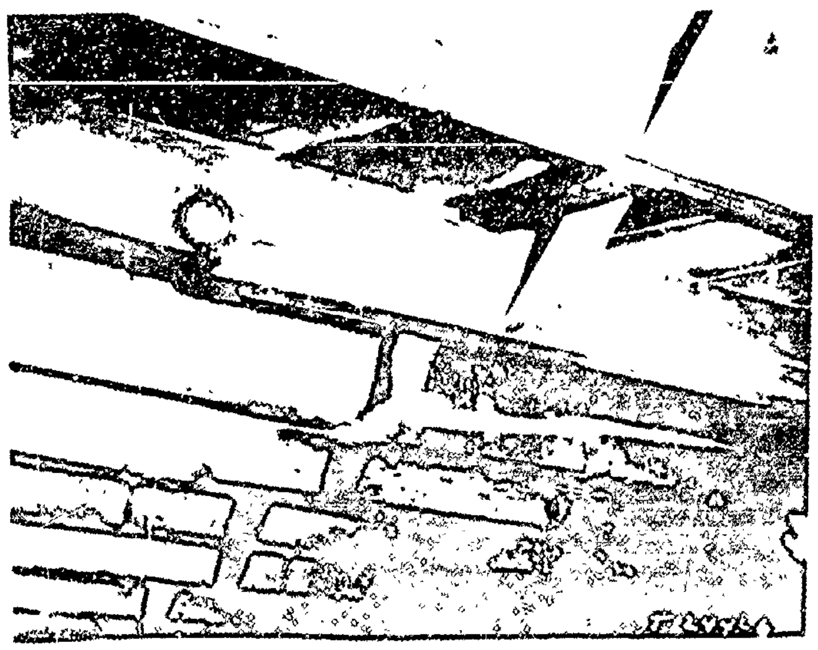


Fig. 3-6. Fractured First Floor Joists Under Living Room, House II-1

Fig. 3-7. Post-Test Photo, House II-2 (front view)

remained where supported by bearing partitions. Many of the second floor joists were not broken or split and acted as cantilevers from the bearing partitions (see Fig. 3-8).

The first floor partially collapsed into the basement as a result of the fracturing of practically all the long-span first floor joists at the center of the spans. This was probably caused both by the overpressure loading and by the load of the second floor which fell upon it. The floor joists were hanging so as to provide little support for the floor except in the area between post and beam supports, the debris being supported by the diaphragm action of the sub- and finish flooring. The floor on each side of the post and beam support was subject to imminent collapse. One wood beam under a bearing partition was badly split. The other wood beam and all four pipe columns appeared in good condition and showed no evidence of movement. The basement stairs remained standing and in good condition. The 12-in. concrete block basement walls below ground level suffered very minor damage, indicating a relatively minor ground shock wave compared to the air shock wave.

The second floor system offered considerable resistance to the external lateral pressure of the blast. It appears that the blast wave, as it enveloped the house, blew in the windows and doors and built up a high overpressure inside the house, at the same time weakening the front wall and probably the others. As the pressure outside dropped off in intensity, the high-pressure volume of air inside the house probably forced the walls outward, collapsing the structure. The second-floor system as designed offered very little resistance to internal lateral pressure since the fire-cut joists were designed to bear on, but were not secured to, the cinder-block wythe of the exterior wall.

Test Description, Houses II-3 and II-4

In March and April 1959 two full-scale tests simulating an accidental detonation of missiles in an underground storage magazine were conducted at the White Sands Missile Test Range in New Mexico. During these tests eight Type II houses were exposed to the air blast from three missile detonations

Fig. 3-8. Post-Test Photo, House II-2 (back view)

Four houses were exposed to a peak incident overpressure of 1.1 psi from an estimated charge weight of 2550 lb, and four houses at a peak overpressure of 1.27 psi from an estimated charge weight of 3500 lb. The house damage information for these tests was obtained from Ref. 6. The data presented in this report was not sufficient to determine the damage to each house, but was adequate to describe that experienced by the most severely damaged house in each test. These houses are identified as Nos. II-3 for the 2500 lb test and II-4 for the test with 3500 lbs of TNT.

Test Results, House II-3

The estimated incident peak overpressure at this house, located 528 ft from an estimated 2550 lbs of TNT, was 1.1 psi. Damage to the main structure members of the house was minor, with damage being limited to seven broken rafters in the front roof. The breaks, in general, occurred where knots were located on the tension side, near the central portions of the members.

Minor plaster damage was prevalent throughout the house, with the only major damage being to the ceiling in the rear bedroom, where approximately 30 sq ft of plaster was removed. Moderate plaster damage was evident across the ceiling of the master bedroom under the built-up beams. The front door, all of the front windows, most of the side windows, and very few of the rear windows were removed. The swinging door between the dining room and kitchen was also removed, and there was some superficial damage to the interior doors at the rear of the center hallway. This consisted of cracking of the door casings at the latches.

Test Results, House II-4

The estimated incident peak overpressure at this house was 1.3 psi. This house was also located 528 ft from the larger, 3500 lb, explosive charge.

Structural damage from this test was much greater than that experienced by House II-3. There were 12 broken rafters at the front of the house, and one broken rafter in the rear. Four joists were broken in the first floor framing, two each under the dining room and living room.

Plaster damage was also much greater, with most of the cracks outlining the plaster boards. There was major ceiling damage to the rear bedroom and under the built-up beams in the master bedroom. Considerable plaster damage was found over the living room doorway.

The front and interior swinging doors were blown off their hinges and in all cases, the door casings were damaged.

All of the front windows, most of the side windows, and a few of the rear windows were broken.

Section 4
TYPE III HOUSE TESTS

CONSTRUCTION DETAILS

Type III houses are one-story, wood-frame, ranch-style houses. They were constructed on a poured-in-place concrete slab at grade, and were of conventional design with the exception of the bathroom, which was designed as an above ground shelter with 8-in. thick reinforced concrete walls and ceiling. Pre-shot photographs and plan and elevation sketches are presented in Figs. 4-1 and 4-2.

TEST DESCRIPTION

Two Type III houses were exposed to the air blast from the 30 kt Apple II nuclear device during Operation TEAPOT. One of the houses (No. III-1) was located 4700 ft from ground zero and the second (No. III-2) was located 10,500 ft from ground zero (see Ref. 2).

TEST RESULTS

Test Results, House III-1

This house, located at 4700 ft from ground zero, experienced an incident peak overpressure of approximately 5.1 psi. The house was demolished beyond repair, with only the reinforced concrete bathroom shelter remaining intact (see Figs. 4-3 and 4-4). The roof was blown off; one section was found 100 ft to the rear of the house. All rafters were split and broken. The side walls at the gable ends were blown outward and landed approximately 75 ft to the rear of the house. A portion of the front wall was still standing, but leaning inward. The observation was made in the original reference that had it not been for the bathroom shelter, which served to give some measure of support to the house, the house would probably have been blown entirely from its slab foundation.

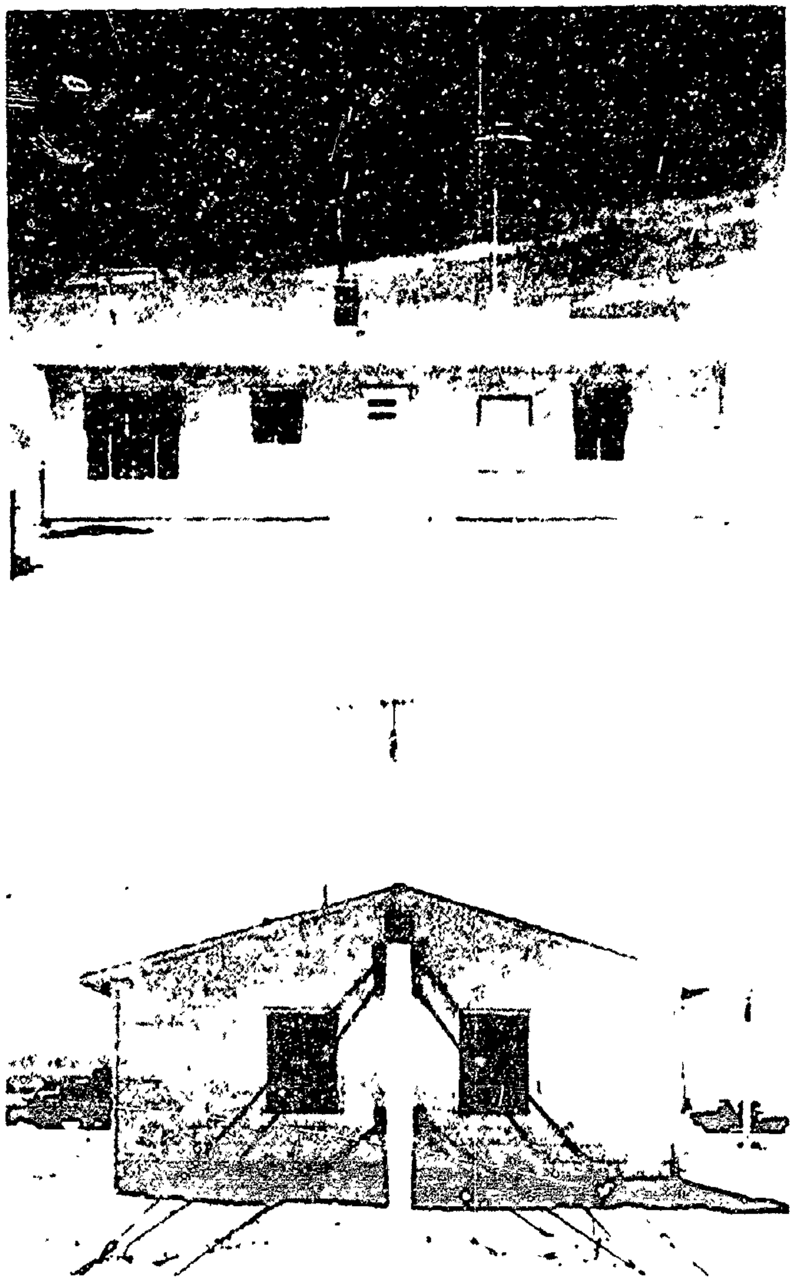


Fig. 1-1. Pre-Test Photos, House III, One-Story, Wood-Frame Ranch-Style

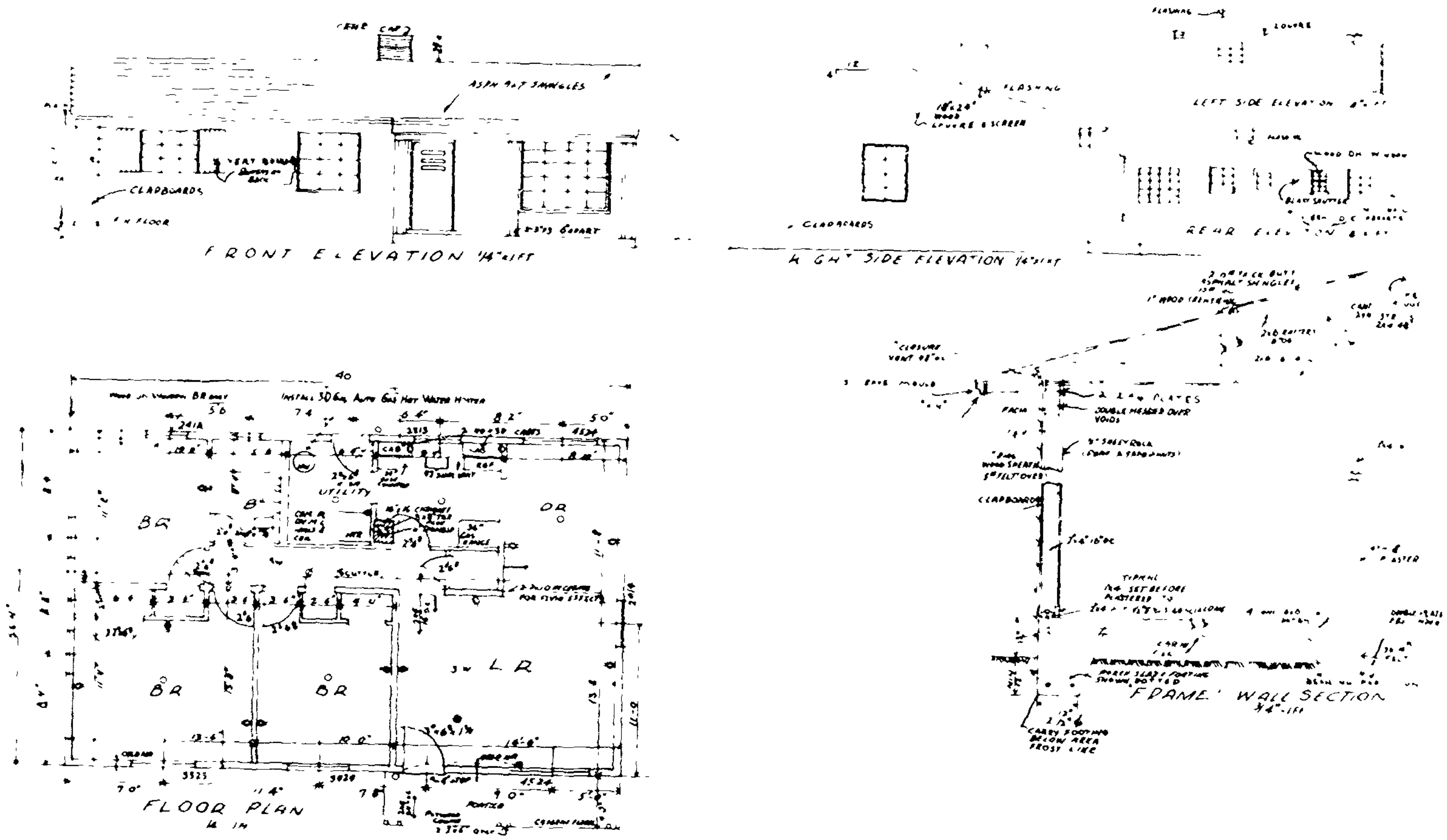


Fig. 4-2. Construction Drawing, House III, One-Story, Wood-Frame Ranch-Style

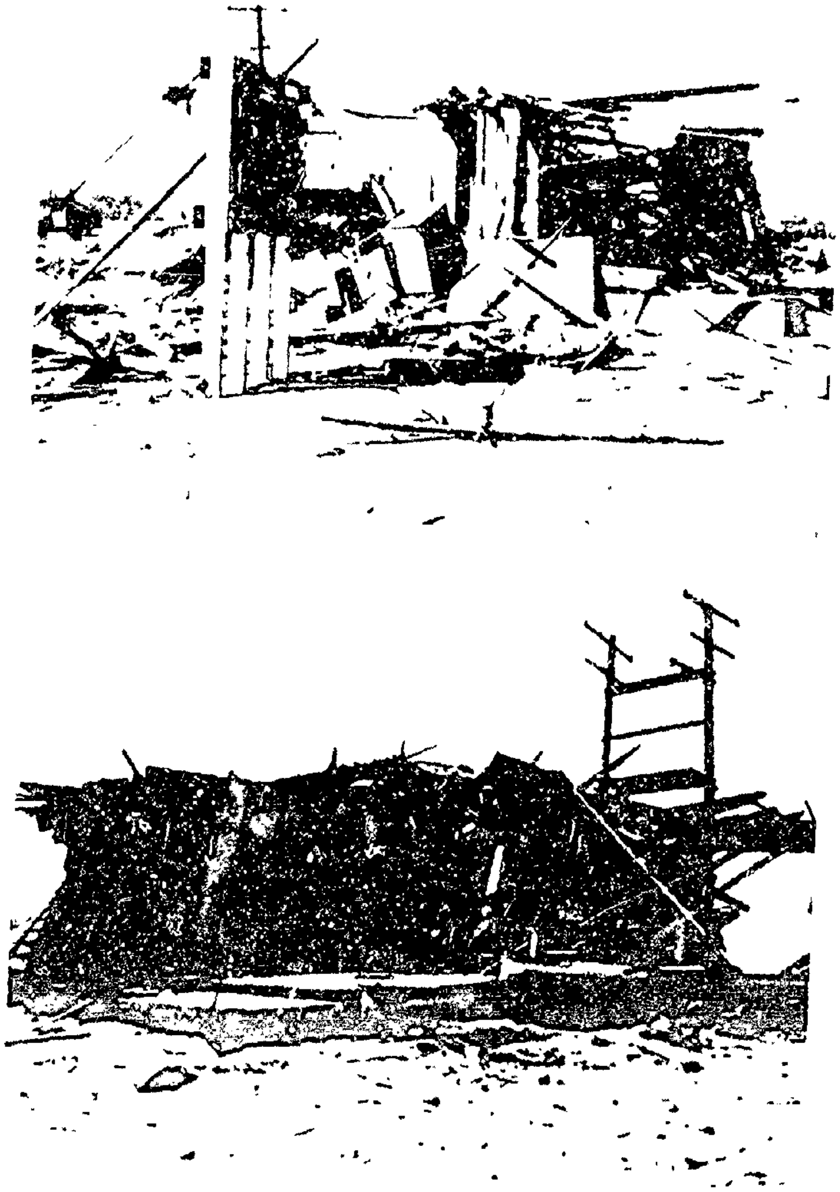


Fig. I-3. Post-Test Photos, House III-1

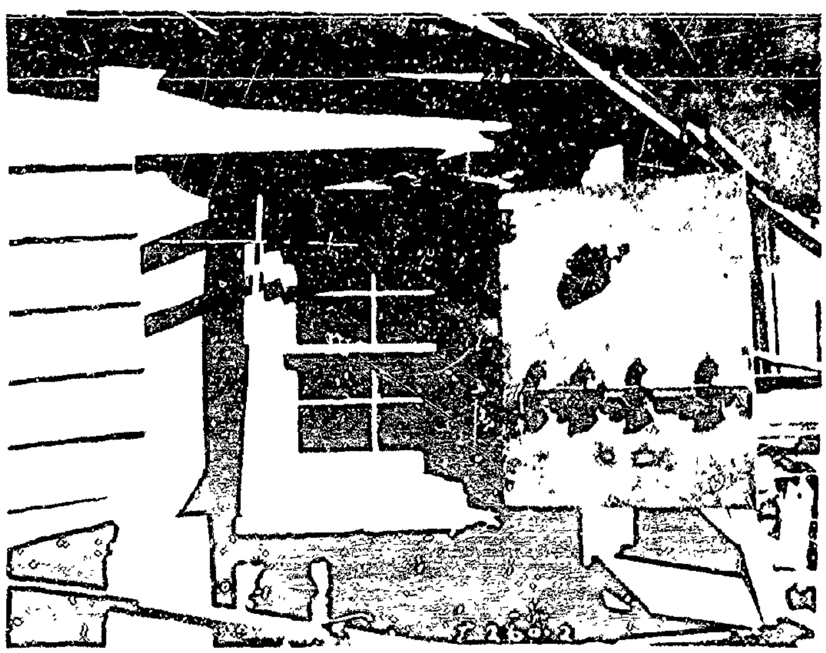


Fig. 4-4. Post-Test Photos, House III-1

Test Results, House III-2

This house was located 10,500 ft from ground zero where measured overpressure was approximately 1.7 psi. This house suffered only minor structural damage (see Fig. 4-5). A 2- by 4-in. stud located between the front door and window was broken, as was a mid-span rafter support beam on the front side.

Considerable damage was done to the plasterboard walls and ceilings (see Fig. 4-6). The glass was completely removed from the front windows and some glass was broken from all of the windows.

Fig. 4-5. Post-Test Photo, Front of House III-2

Fig. 4-6. Post-Test Photo, Ceiling Damage, House III-2

Section 5
TYPE IV HOUSE TESTS

CONSTRUCTION DETAILS

The Type IV houses were two-story brick structures with load-bearing walls. These structures were approximately 40- by 30- by 36-ft high and are representative of urban construction found in many cities in Europe. These structures had metal roofs, wood rafters, and wood floor joists, with the interior partitions which supported the ceiling and floor joists of bearing wall masonry construction (see Figs. 5-1 and 5-2). The structures were oriented face-on to the blast since the heavy masonry bearing walls constitute shear walls which make the structures less vulnerable in this direction.

TEST DESCRIPTION

Two Type IV houses were exposed to the air blast from a 50 kt nuclear device during Operation GREENHOUSE, conducted at Eniwetok Atoll in the Pacific. One of the houses (Type IV-1) was located 4245 ft from ground zero. The second house (Type IV-2) was located 7020 ft from ground zero (see Ref. 7).

TEST RESULTS

Test Results, House IV-1

This house was located 7020 ft from ground zero where the incident peak overpressure was 3.6 psi. Reference 7, from which the damage information was obtained, estimated the blast damage to be 10 percent.

Doors and windows all were blown in. The roof rafters of this building remained; the forward section laid flat and the rear section was in semi-collapse. Distribution of roof debris is shown in Fig. 5-3. Practically no heavy materials were blown away from the building. Although collapsed and partly wracked, the roof framing remained virtually intact and fell in place on the

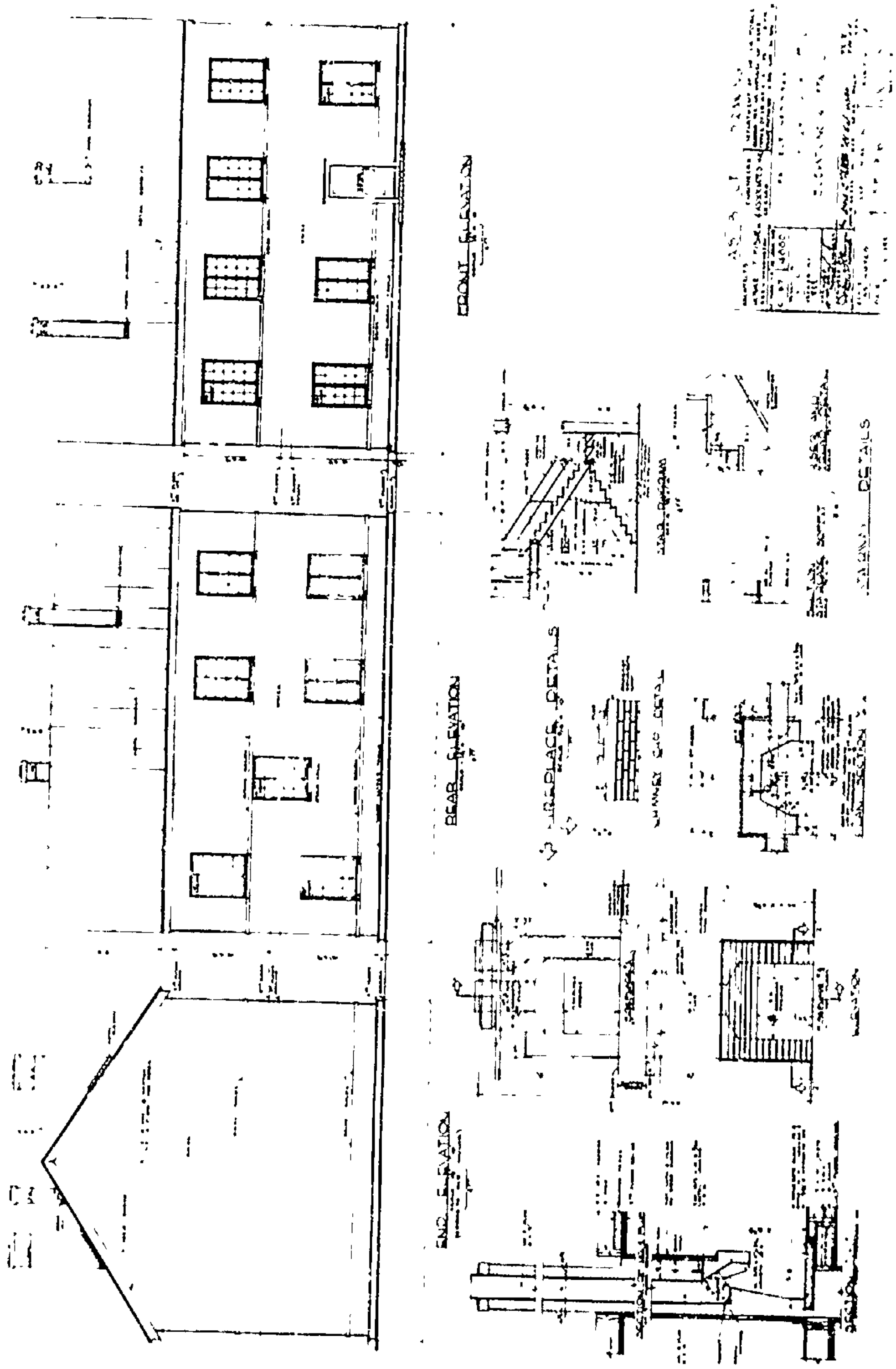


Fig. 5-1. Construction Drawing, Type IV House

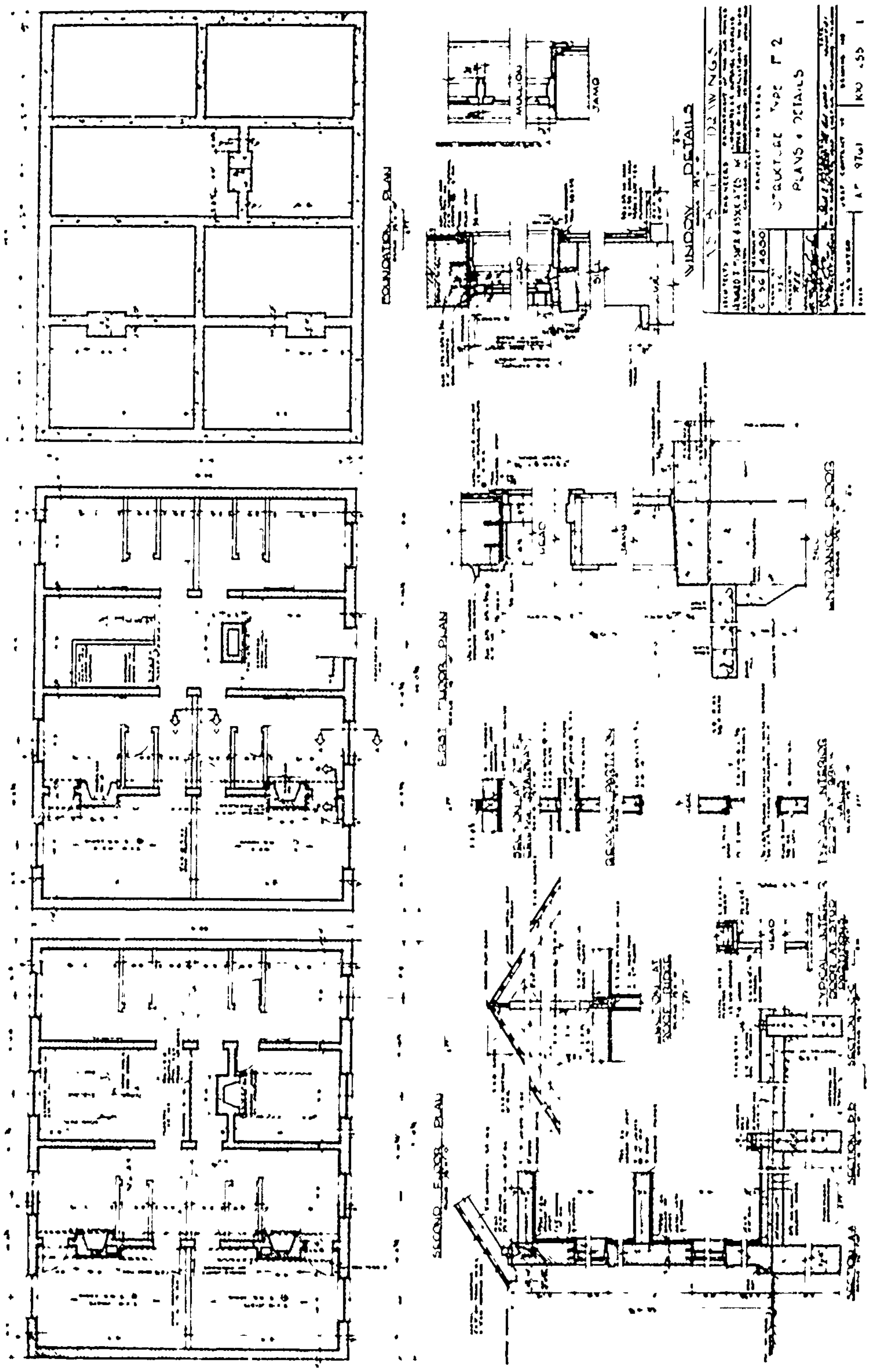


Fig. 5-2. Construction Drawing, Type IV House

Fig. 5-3. Post-Test Photo, House IV-1, Showing Distribution of Roof Debris

top of the building. A number of roof sheets were scattered over a considerable area around the building, generally to the right and to the rear, out to about 75 yd in each direction, although some are seen in front of the building also, as much as 75 yd ahead of the front wall. About 10 percent of the roof sheets lay on the top of the structure; however, all but those referred to above were completely separated from any of the roof framing. The action of the roof under the blast load can be seen in Figs. 5-4, 5-5, and 5-6, which are a series of enlargements made from single frames of the motion pictures taken of this building.

The central chimney broke off at the level of the attic floor and dropped in several sections on the ceiling over the stairwell. The left rear chimney was cracked through at the level of the roof, but, although it was slightly displaced, it did not fall. About 80 percent of the fill-in brickwork under the eaves was racked and displaced. The gable of the right wall was cracked through on a horizontal line about 3-1/2 ft down from the peak. Except for this, there was no visible damage to any of the brick walls. Figures 5-7, 5-8, and 5-9 are general views of house No. IV-1 in the post-test condition.

The partition forward of the upper central hall was backed up by the structure of the central chimney and showed no displacement. All other partitions visible through the openings in the forward wall showed permanent rearward bulging. It is only in the unsymmetrical section of the left side of the building that the load-bearing partitions were directly exposed to the blast wave entering the front windows, and it was only the outside lower left partition which failed enough that it was unable to continue its supporting function (see Fig. 5-10).

The load-bearing partition directly above this on the second floor suffered similar damage although to a lesser degree. Although both partitions were constructed to like structural specifications, the one on the second floor did not buckle so severely as the lower one. It is believed that both partitions were subjected to like loading and that the difference in damage was due to normal variations inherent in this type of construction. All load-bearing partitions

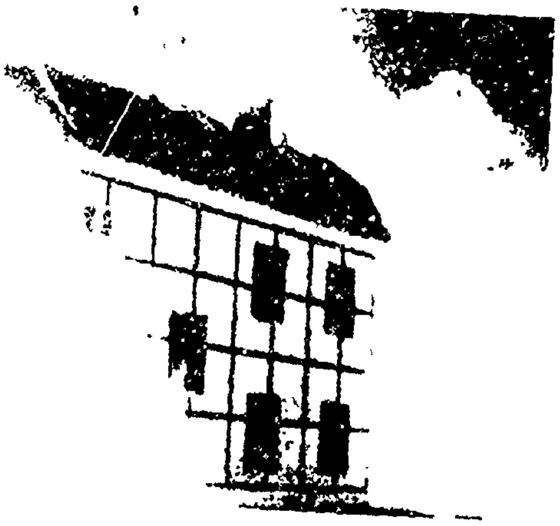


Fig. 5-1. Rear of House IV-1 Just After Arrival of Shock Wave

Fig. 5-5. Rear of House IV-1 0.6 sec After Arrival of Shock Wave

Fig. 5-6. Rear of House IV-1 1.0 sec After Arrival of Shock Wave

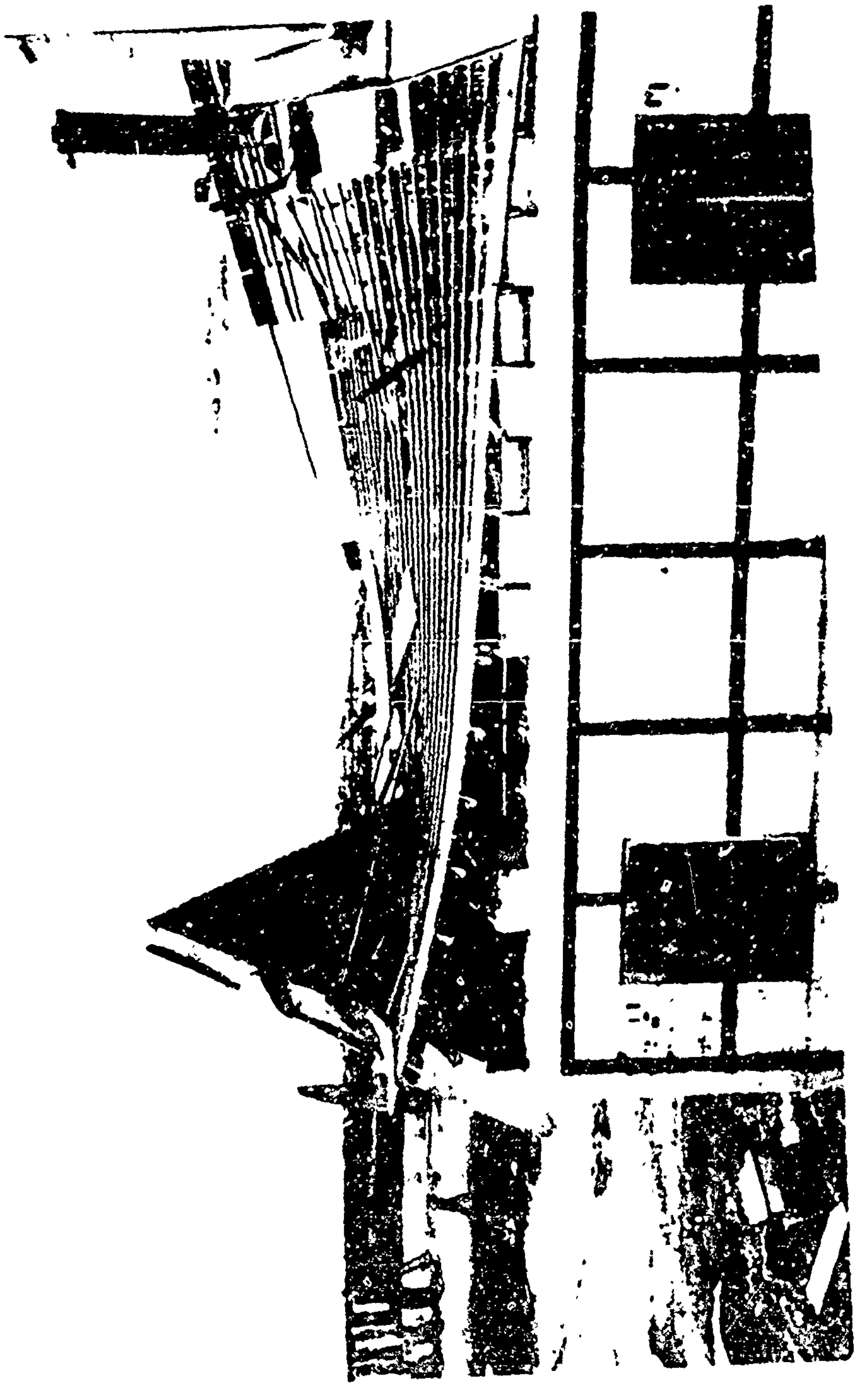


Fig. 5-7. Post-Test Photo, Right Side of House IV-1 (viewed from the rear)

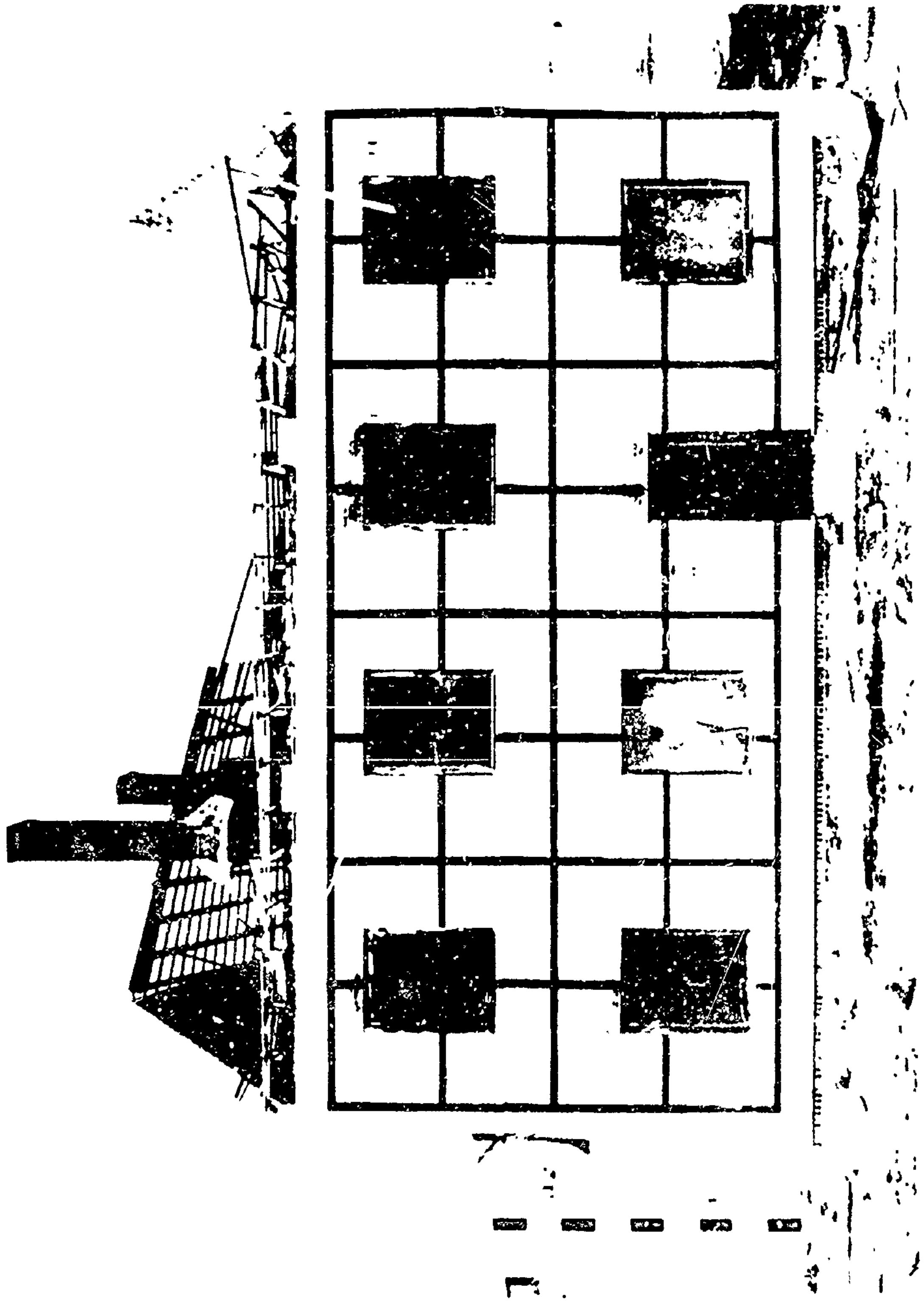


Fig. 5-8. Post-Test View, Rear of House IV-1

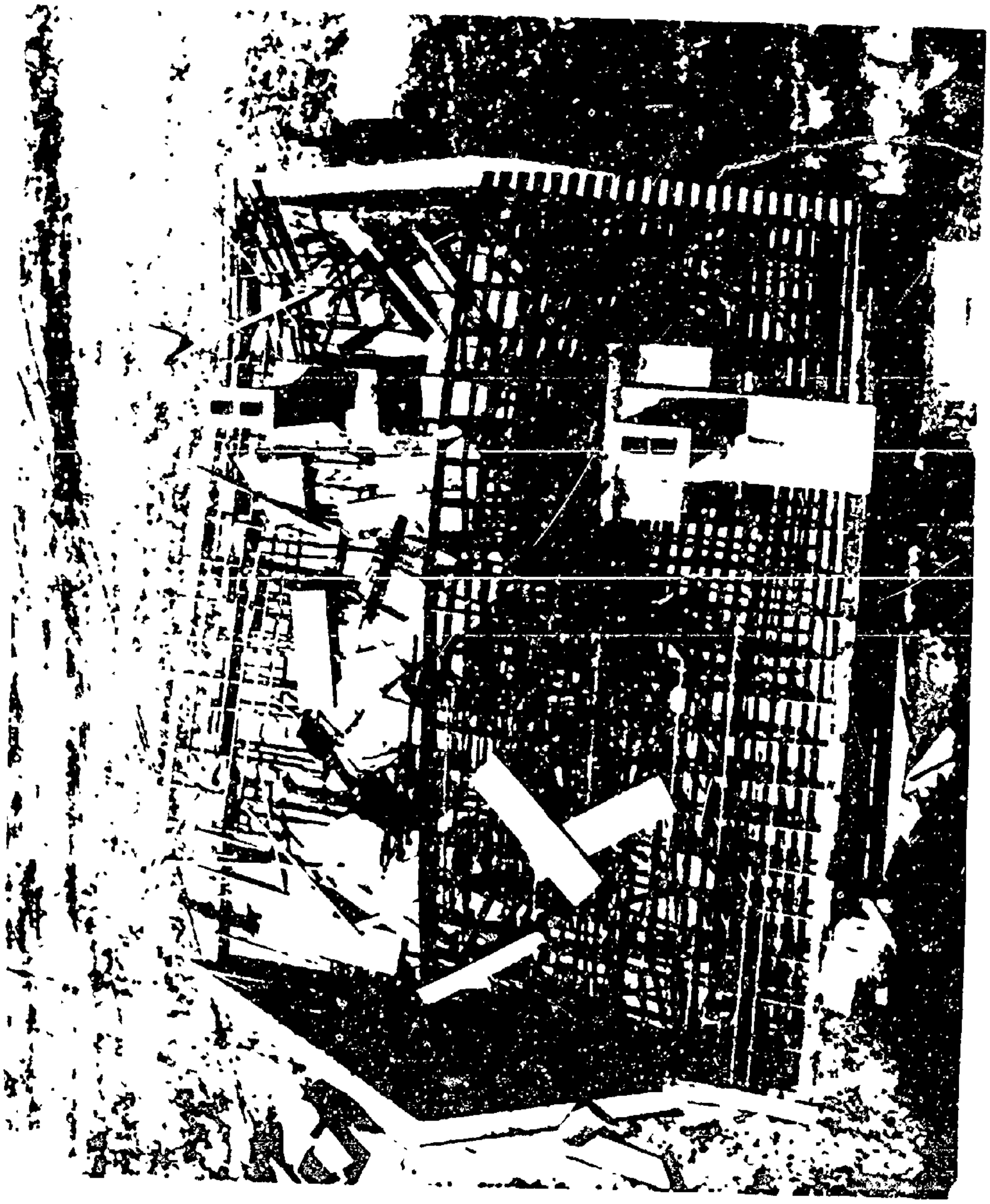


Fig. 5-9. Post-Test Aerial View, House IV-1

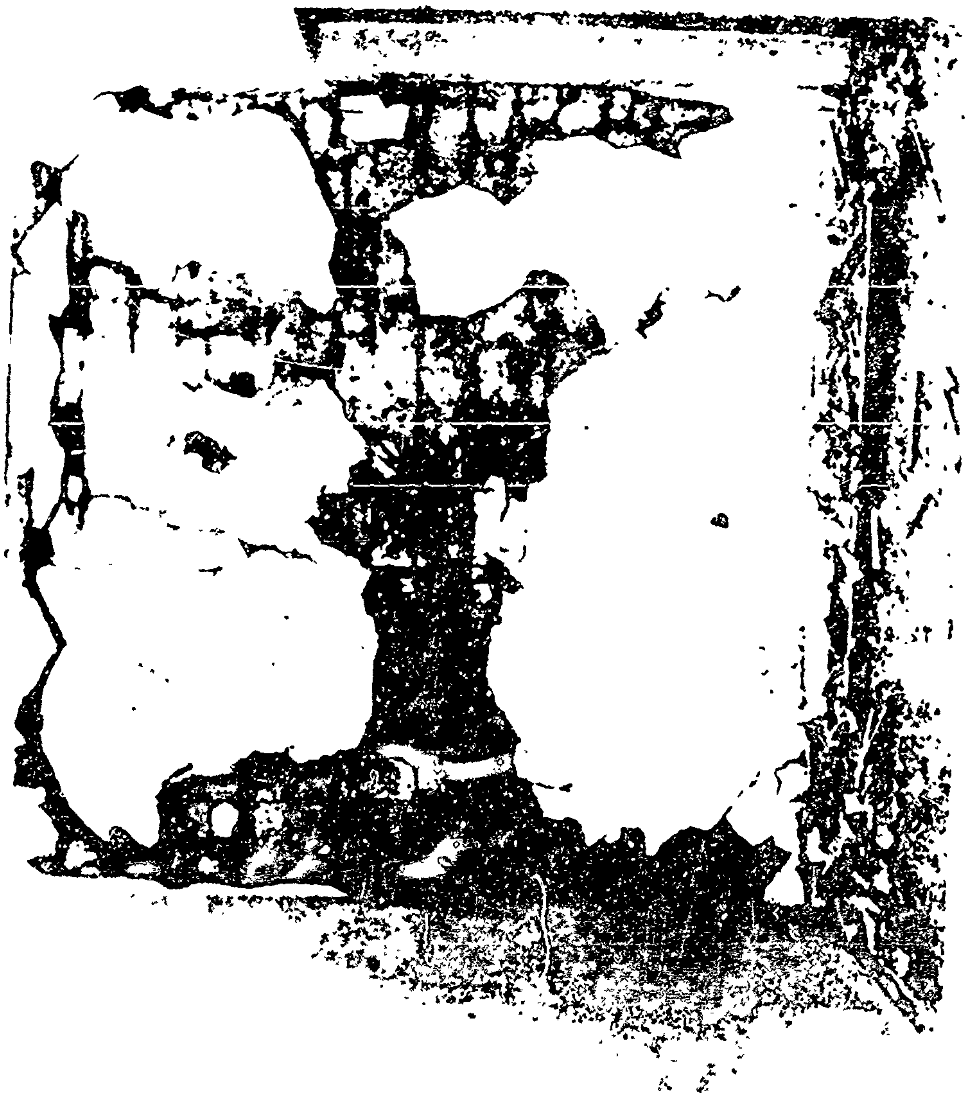


Fig. 5-10. Post-Test Photo, Front Side of House IV-1 (toward blast)

consisted of 2- by 6-in. studs with 2- by 6-in. top and bottom plates. These were covered by 1/2 in. of plaster on metal lath.

The forward ceilings on the upper story were usually cracked at the corners as by an upward pressure; the corresponding rear ceilings were bowed downward.

Test Results, House IV-2

This house was located at 4245 ft from ground zero where the incident peak overpressure was 9 psi. Reference 7, from which this damage information was obtained, estimated the blast damage to be 40 percent.* Above the second story this structure was razed; the chimneys were toppled, and the roofing and roof rafters were carried away. Both brick gables fell vertically to positions beneath their original locations: the left wall was toppled as a unit to the side, and the forward 75 percent of the right wall was blown out to the side in two sections separated along the line of the first floor ceiling. (Here, and throughout this section, right and left are defined with the observer's back to ground zero.) With the exception of one pane of glass which remained in the window above the stair landing, all glass in the building was blown in. Doors were blown off or were broken off beyond the rear stile. Figures 5-11 through 5-14 are photographs showing general aspects of the blast-damaged building.

The roof debris is shown in Fig. 5-15. The distribution of this debris, metal roof, sheathing, stringers, and rafters was heaviest in the right rear quadrant, within 75 yd to the right of the building and 75 yd to the rear. A concentrated piling of the roof rafters was located 6 yd to the right and 19 yd to the rear of this corner of the building. About 15 of the roof sheets, several splintered rafters, and portions of the chimney framing were scattered over an area to the right of the building center line and within 100 yd ahead of the forward wall.

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* This damage estimate has been reevaluated during the preparation of this report. See the discussion in Section 7.

Fig. 5-11. Post-Test, Front View of House IV-2

Fig. 5-12. Post-Test, Right Side of House IV-2

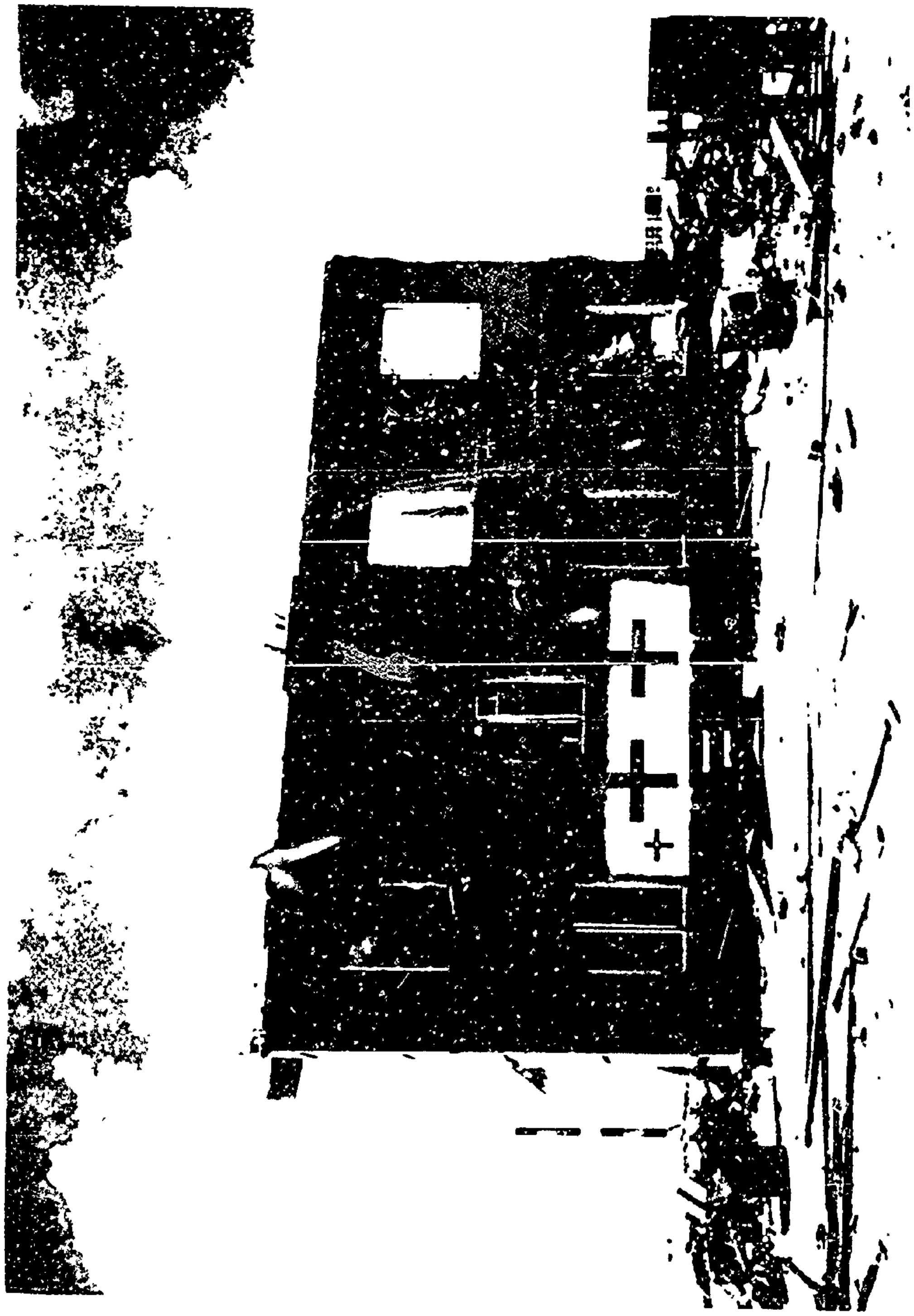


Fig. 5-13. Post-Test, Rear View of House IV-2

Fig. 5-14. Post-Test, Left Side of House IV-2

Fig. 5-15. Post-Test, Aerial View of House IV-2

In general, the first interior partition to meet the pressure wave was either collapsed or pushed rearward, while the second partition in the line received only plaster damage. The front closet partitions bent under the blast, the upper and lower nailed joints sheared, and the partitions collapsed back against the second closet partition just to the rear. The three load-bearing partitions on each floor of the structure did not fail in bending but were blown back when the upper and lower connections failed in shear. The final condition of these partitions is shown in Figs. 5-16 and 5-17.

The assymmetrical section on the far left side of the building was almost completely collapsed, as can be seen in Fig. 5-18. In this section, only the rear brick wall and 75 percent of the forward brickwork remained. Missing from this side of the forward wall were the sections above and to the left of the upper window. The vertical brickwork at the side of the window was carried to the side; the horizontal section above the window fell out to the front. The floor structure between the first and second levels in this section collapsed downward in bending along the front-to-rear line of its connection with the interior brick shear wall. Ceiling sections above the second level fell intact down on top of the rubble and suffered only plaster damage. The final orientation of these sections was bottom up; they were completely separated from their supports.

Forward upper story ceilings in the symmetrical sections on either side of the central hall, and in the room above the front door, were displaced upward about an inch by the blast pressure. In the rear of the building the upper ceilings were pushed downward to collapse. The collapse of the ceiling section above the stairwell was aided by the rearward fall of the chimney above the central hall.

With the exception of the upper left corner of the forward wall, both front and rear walls remained in place. The front wall was cracked vertically along the shear walls at either side of the lower hall. These cracks, hairline to 1/8-in. wide, were visible on the outside surface only and extended from the foundation up to the brick cornice below the upper windows. Similar cracks were visible along the foundation line at the central hall and at window corners

Fig. 5-16. Post-Test Photo, Right Side of House IV-2, Showing Partition Damage

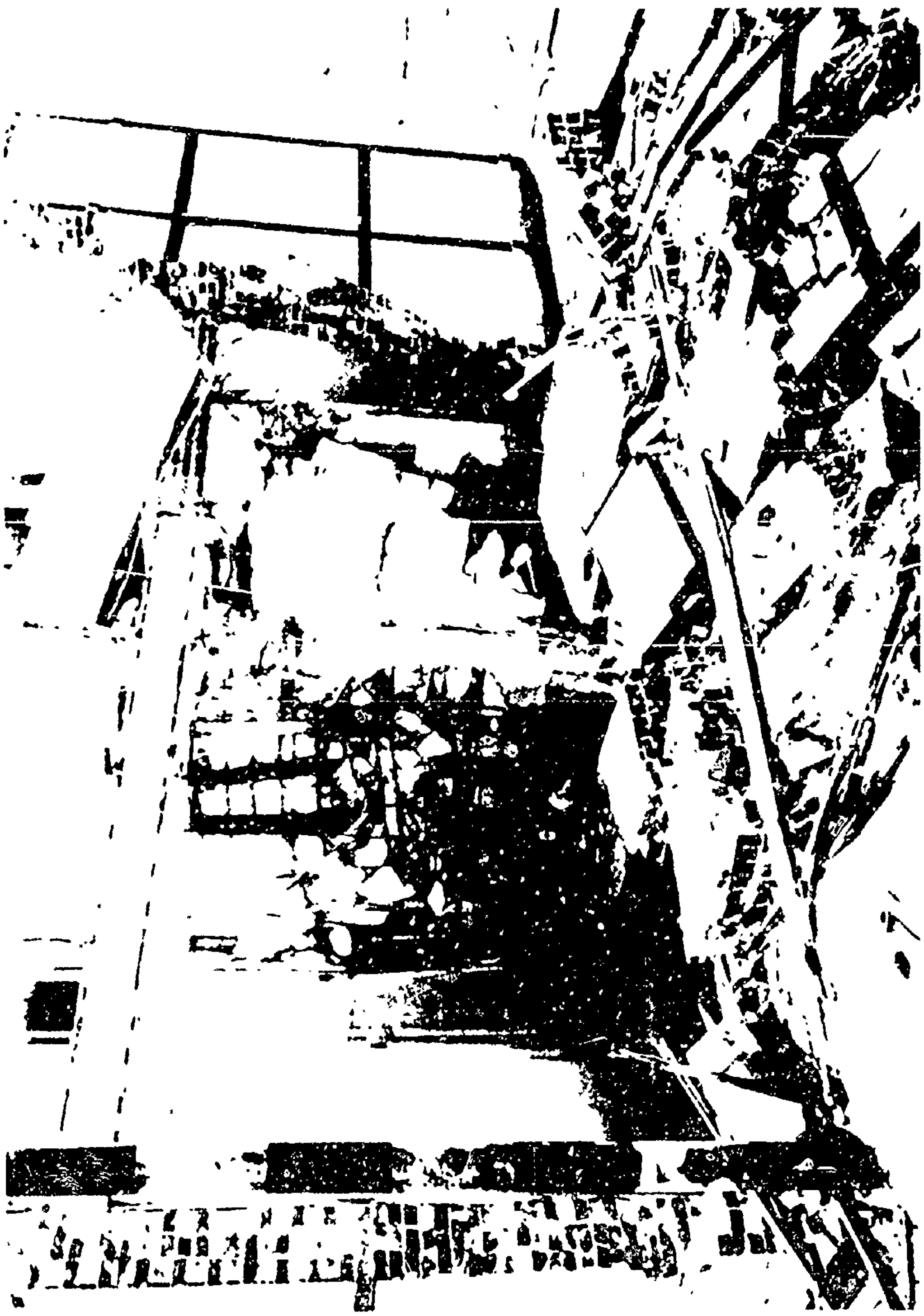


Fig. 5-17. Post-Test Photo, Right Side of House IV-2, Showing Close-Up of Wall and Partition Damage

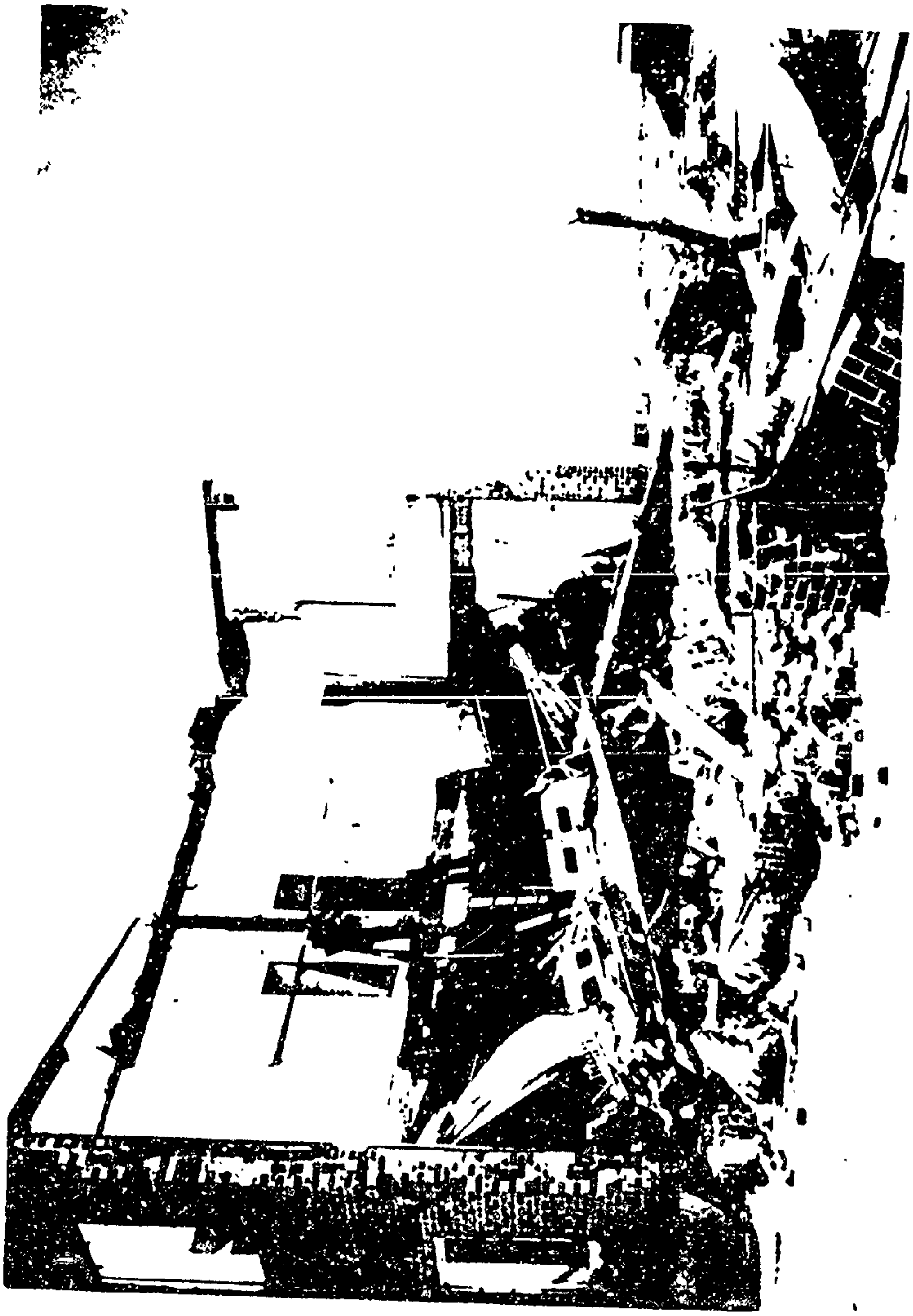


Fig. 5-18. Post-Test Photo, Left Side of House IV-2 (viewed from the rear)

at the lower left of the front wall. On both front and rear walls the brick-work filler under the eaves and between rafters was cracked, and only about 10 percent of the filler remained in place after the blast.

No cracks were visible in the rear wall proper. The wall section in the upper stairwell, however, was bulged outward between 1 and 2 in. and was separated from the adjacent shear walls.

Section 6

DAMAGE QUANTITIES
(Objective Assessment)

In Sections 2 through 5 the various test houses were described, and the damage sustained by them on each test was presented in considerable detail. It is frequently difficult, however, from such descriptions, to come to any conclusions about the relative damage sustained by each house, that is, it is difficult to determine whether a house was damaged more as a result of one test than another.

For example, House I-6 (exposed to 1.2 psi from a 10,000 lb charge) experienced significant chimney damage, but there was only one rafter cracked. House I-7 (exposed to 1.1 psi from a 1,000,000 lb charge) experienced insignificant damage, but 19 out of 26 rafters in the front of the roof failed. Which of the two houses sustained "more" damage?

In this section of the report, a cost-oriented, quantitative approach is developed which allows such comparisons to be made. It is described as an "objective assessment" of damage, at least in part because different evaluators of damage, using the approach, should come up with the same estimates of damage quantities. In a sense the results are repeatable, and can, therefore, be compared with confidence.

DAMAGE ASSESSMENT PROCEDURE

The damage evaluation procedure used in this section required that the plans and specifications for each of the house types, I through IV, be subjected to a bid analysis procedure commonly used throughout the construction industry. This procedure involves dividing the house in question into its various component parts and (1) calculating the yards of concrete, board feet of lumber, square feet of shingles, linear feet of siding, etc., which were needed to construct the particular type of house; and (2) estimating the hours of labor required to install these various component parts. The result of these

computations is an estimate of the dollar value of these various components which can then be expressed as a percentage of the total value of the house.

The typical breakdown for the various groups of components that make up a Type I (two-story wood frame) house is presented in Table 6-1. The numbers are expressed as a percentage of the total value of the structure.

To perform a damage estimate of a particular house, the quantities of materials damaged (i.e., the number of studs split, the square feet of plaster removed or damaged, the panes of glass broken, etc.) were then computed, and the percentages of each of the elements, shown in Table 6-1, that were damaged or destroyed were determined. By multiplying these percentages by the percent of total value estimate for each of the elements, of Table 6-1, a total damage estimate expressed in percent of the total value of the structure is derived.

SUMMARY OF DAMAGE DATA

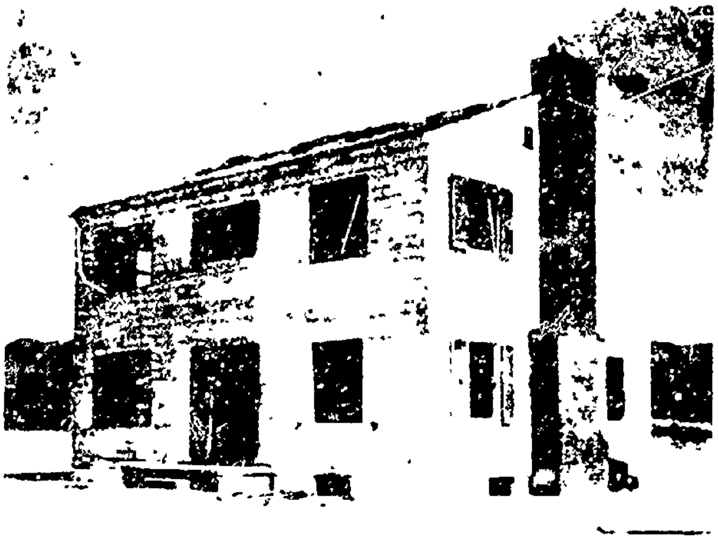
The results of this damage estimate procedure for each of the two-story wood-frame Type I houses is presented in Figs. 6-1 through 6-11. Presented in each of these figures are a post-test photo of the house; the test parameters including the peak overpressure, positive phase impulse, charge size and ground range; and the damage data expressed both as a percentage of each element that was damaged or destroyed, and as a percentage of the total value of the structure.

Similar data for the Type II, III and IV houses are presented in Figs. 6-12 through 6-19. For these houses, tables of component group values similar to Table 6-1 were not prepared; instead the values of Table 6-1 itself were used.

Table 6-1

VALUE OF COMPONENT GROUPS FOR TYPE I HOUSE

ITEM	VALUE % OF TOTAL
Floor & Ceiling Framing	17
Roof Framing & Roof Surface	7
Exterior & Interior Wall Framing	16
Interior Plaster	11
Exterior Sheathing & Siding	8.6
Doors	4.6
Windows	4.8
Foundation & Basement	19
Miscellaneous: Stairs, Fireplace, Paint, Trim	12
Total	100



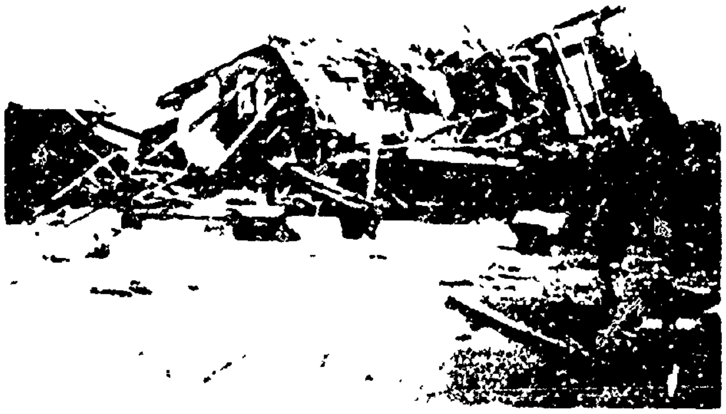
Peak Overpressure (psi) 1.[illegible]
Charge Size (kt) 16.2

Positive Phase Impulse (psi-msec) ~ 900
Ground Range (ft) 7500

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	12	2.0
Roof Framing and Roof Surface	35	2.5
Exterior and Interior Wall Framing	9	1.4
Interior Plaster	5	0.6
Exterior Sheathing and Siding	0	0
Doors	50	2.3
Windows	88	4.2
Foundation and Basement	0	0
Misc.: Stairs, Fireplace Paint, Trim	6	0.7
TOTAL		13.7

Fig. 6-1. House Damage Summary, House No. I-1



Peak Overpressure (psi) 5.0
Charge Size (kt) 16.2

Positive Phase Impulse (psi-msec) ~ 1750
Ground Range (ft) 3500

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	100	17.0
Roof Framing and Roof Surface	100	7.0
Exterior and Interior Wall Framing	100	16.0
Interior Plaster	100	11.0
Exterior Sheathing and Siding	100	8.6
Doors	100	4.6
Windows	100	4.8
Foundation and Basement	3	0.6
Misc.: Stairs, Fireplace, Paint, Trim	100	12.0
TOTAL		81.6

Fig. 6-2. House Damage Summary, House No. 1-2

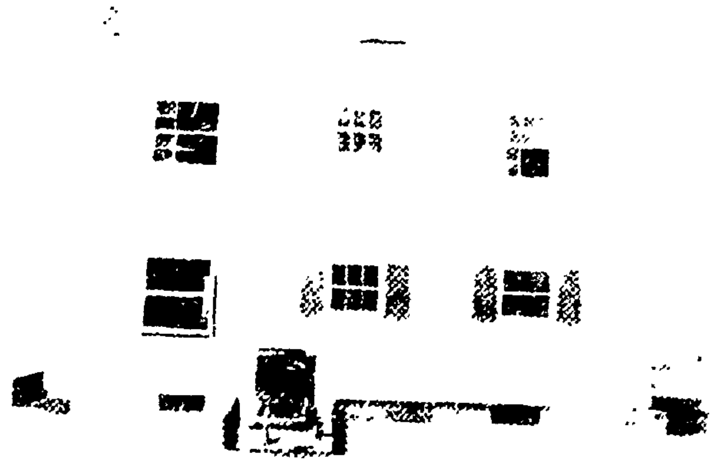
Peak Overpressure (psi) 4.0
Charge Size (kt) 30.0

Positive Phase Impulse (psi-msec) ~ 1630
Ground Range (ft) 5500

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	20	3.4
Roof Framing and Roof Surface	100	7.0
Exterior and Interior Wall Framing	8	1.3
Interior Plaster	30	3.3
Exterior Sheathing and Siding	25	2.2
Doors	100	4.6
Windows	100	4.8
Foundation and Basement	0	0
Misc.: Stairs, Fireplace Paint, Trim	75	9.0
TOTAL		35.6

Fig. 6-3. House Damage Summary, House No. I-3



Peak Overpressure (psi) 2.6
Charge Size (kt) 30.0

Positive Phase Impulse (psi-msec) ~ 1150
Ground Range (ft) 7800

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	0	0
Roof Framing and Roof Surface	33	2.3
Exterior and Interior Wall Framing	4	0.6
Interior Plaster	30	3.3
Exterior Sheathing and Siding	9	0.8
Doors	50	2.3
Windows	100	4.8
Foundation and Basement	0	0
Misc.: Stairs, Fireplace, Paint, Trim	30	3.6
TOTAL		17.7

Fig. 6-4. House Damage Summary, House No. I-4

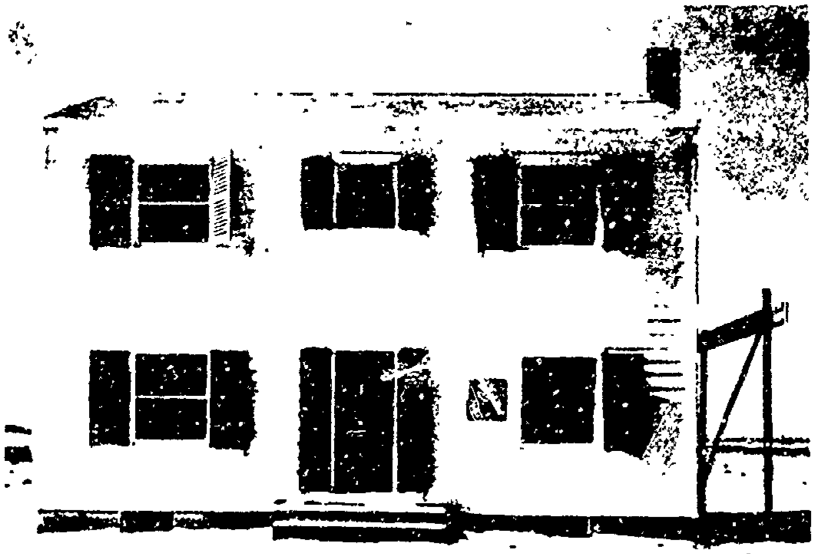
788-5

Peak Overpressure (psi) 1.3
Charge Size (lb) 10,000
Positive Phase Impulse (psi-msec) ~ 47
Ground Range (ft) 865

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	0	0
Roof Framing and Roof Surface	1	0.1
Exterior and Interior Wall Framing	0	0
Interior Plaster	6	0.7
Exterior Sheathing and Siding	0	0
Doors	20	0.9
Windows	44	2.1
Foundation and Basement	0	0
Misc.: Stairs, Fireplace, Paint, Trim	12	1.4
TOTAL		5.2

Fig. 6-5. House Damage Summary, House No. I-5

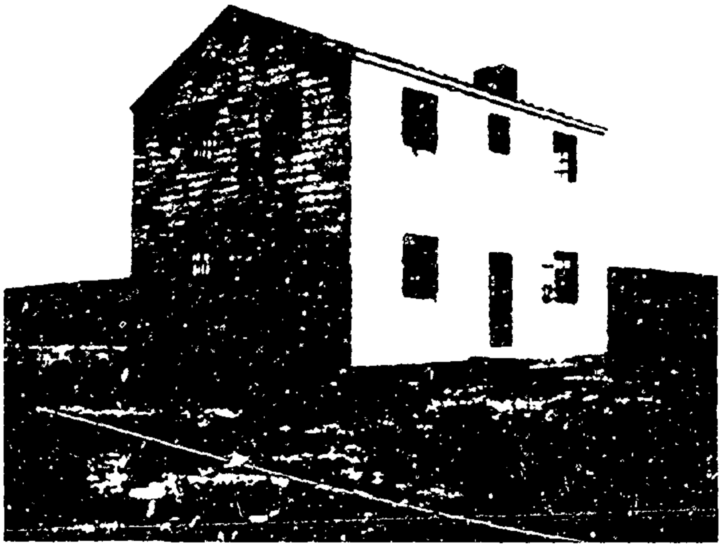


Peak Overpressure (psi) 1.2
Charge Size (lb) 10,000
Positive Phase Impulse (psi-msec) ~ 44
Ground Range (ft) 865

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	0	0
Roof Framing and Roof Surface	3	0.2
Exterior and Interior Wall Framing	0	0
Interior Plaster	6	0.7
Exterior Sheathing and Siding	0	0
Doors	20	0.9
Windows	61	2.9
Foundation and Basement	0	0
Misc.: Stairs, Fireplace, Paint, Trim	15	1.8
TOTAL		6.5

Fig. 6-6. House Damage Summary, House No. I-6

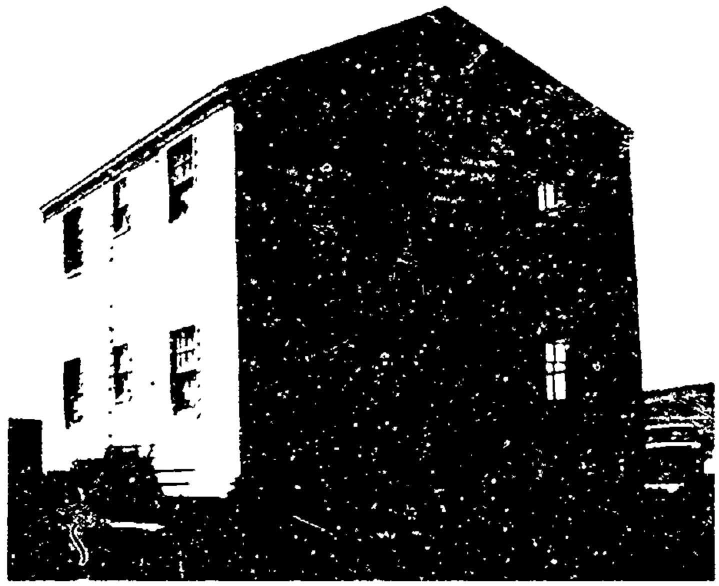


Peak Overpressure (psi) 1.1
Charge Size (ton) 500
Positive Phase Impulse (psi-msec) ~ 185
Ground Range (ft) 4000

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	0	0
Roof Framing and Roof Surface	14	1.0
Exterior and Interior Wall Framing	3	0.5
Interior Plaster	5	0.6
Exterior Sheathing and Siding	0	0
Doors	18	0.8
Windows	47	2.3
Foundation and Basement	0	0
Misc.: Stairs, Fireplace, Paint, Trim	3	0.4
TOTAL		5.6

Fig. 6-7. House Damage Summary, House No. I-7

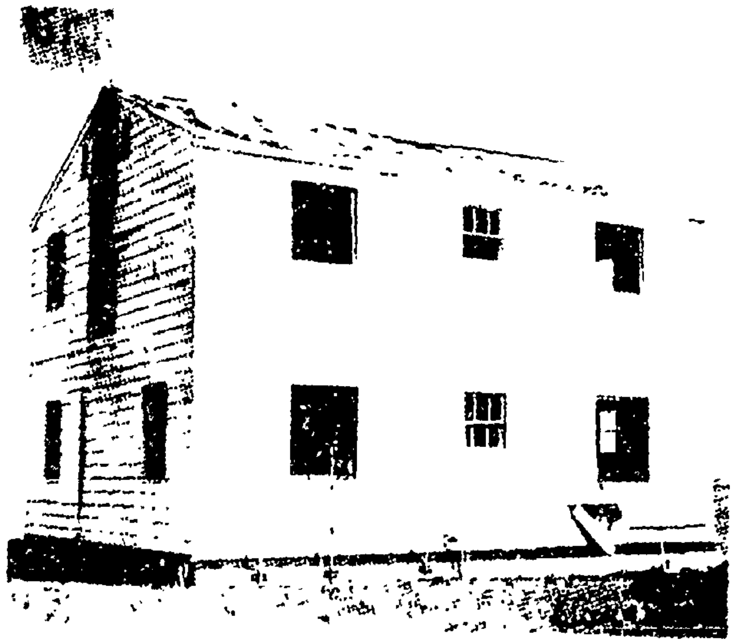


Peak Overpressure (psi) 1.6
Charge Size (ton) 100
Positive Phase Impulse (psi-msec) ~ 161
Ground Range (ft) 1660

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	0	0
Roof Framing and Roof Surface	27	1.9
Exterior and Interior Wall Framing	7	1.1
Interior Plaster	25	2.8
Exterior Sheathing and Siding	2	0.2
Doors	17	0.8
Windows	55	2.6
Foundation and Basement	0	0
Misc.: Stairs, Fireplace, Paint, Trim	12	1.4
TOTAL		10.8

Fig. 6-8. House Damage Summary, House No. I-8



Peak Overpressure (psi) 2.7
Charge Size (ton) 500

Positive Phase Impulse (psi-msec) ~ 340
Ground Range (ft) 2256

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	0	0
Roof Framing and Roof Surface	60	4.2
Exterior and Interior Wall Framing	23	3.7
Interior Plaster	40	4.4
Exterior Sheathing and Siding	20	1.7
Doors	67	3.1
Windows	93	4.5
Foundation and Basement	0	0
Misc.: Stairs, Fireplace, Paint, Trim	30	3.6
TOTAL		25.2

Fig. 6-9. House Damage Summary, House No. I-9

No Photo Available

Peak Overpressure (psi) 1.1
Charge Size (lb) 2550
Positive Phase Impulse (psi-msec) ~ 28
Ground Range (ft) 528

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	0	0
Roof Framing and Roof Surface	9	0.6
Exterior and Interior Wall Framing	2	0.3
Interior Plaster	5	0.6
Exterior Sheathing and Siding	0	0
Doors	17	0.8
Windows	53	2.4
Foundation and Basement	0	0
Misc.: Stairs, Fireplace, Paint, Trim	8	1.0
TOTAL		5.7

Fig. 6-10. House Damage Summary, House No. I-10

No Photo Available

Peak Overpressure (psi) 1.3
Charge Size (lb) 3500
Positive Phase Impulse (psi-msec) ~ 46
Ground Range (ft) 528

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	0	0
Roof Framing and Roof Surface	12	0.8
Exterior and Interior Wall Framing	4	0.6
Interior Plaster	13	1.4
Exterior Sheathing and Siding	0	0
Doors	17	0.8
Windows	73	3.5
Foundation and Basement	0	0
Misc.: Stairs, Fireplace, Paint, Trim	8	1.0
TOTAL		8.1

Fig. 6-11. House Damage Summary, House No. I-11

Peak Overpressure (psi) 1.9 | Positive Phase Impulse (psi-msec) ~ 810
Charge Size (kt) 30.0 | Ground Range (ft) 10,500

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	12	2.0
Roof Framing and Roof Surface	30	2.1
Exterior and Interior Wall Framing	0	0
Interior Plaster	15	1.7
Exterior Sheathing and Siding	0	0
Doors	17	0.8
Windows	80	3.8
Foundation and Basement	0	0
Misc.: Stairs, Fireplace, Paint, Trim	1	0.5
TOTAL		10.9

Fig. 6-12. House Damage Summary, House No. II-1

Peak Overpressure (psi) 5.1 Positive Phase Impulse (psi-msec) ~ 1850
Charge Size (kt) 30.0 Ground Range (ft) 4700

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	100	17.0
Roof Framing and Roof Surface	100	7.0
Exterior and Interior Wall Framing	100	16.0
Interior Plaster	100	11.0
Exterior Sheathing and Siding	100	8.6
Doors	100	4.6
Windows	100	4.8
Foundation and Basement	2	0.4
Misc.: Stairs, Fireplace, Paint, Trim	100	12.0
TOTAL		81.4

Fig. 6-13. House Damage Summary, House No. II-2

No Photo Available

Peak Overpressure (psi) 1.1
Positive Phase Impulse (psi-msec) ~ 28
Charge Size (lb) 2550
Ground Range (ft) 528

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	0	0
Roof Framing and Roof Surface	8	0.6
Exterior and Interior Wall Framing	0	0
Interior Plaster	3	0.3
Exterior Sheathing and Siding	0	0
Doors	17	0.8
Windows	68	3.3
Foundation and Basement	0	0
Misc.: Stairs, Fireplace, Paint, Trim	4	0.5
TOTAL		5.5

Fig. 6-14. House Damage Summary, House No. I1-3

No Photo Available

Peak Overpressure (psi) 1.3 Positive Phase Impulse (psi-msec) ~ 46
Charge Size (lb) 3500 Ground Range (ft) 528

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	5	0.9
Roof Framing and Roof Surface	13	0.9
Exterior and Interior Wall Framing	0	0
Interior Plaster	5	0.6
Exterior Sheathing and Siding	0	0
Doors	17	0.1
Windows	78	3.7
Foundation and Basement	0	0
Misc.: Stairs, Fireplace, Paint, Trim	8	1.0
TOTAL		7.2

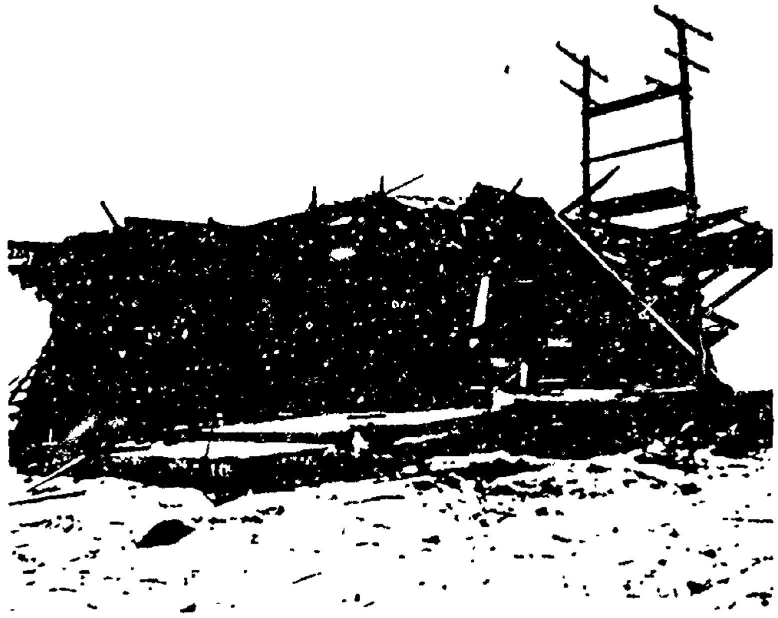
Fig. 6-15. House Damage Summary, House No. II-4

Peak Overpressure (psi) 1.9 Positive Phase Impulse (psi-msec) ~ 810
Charge Size (kt) 30.0 Ground Range (ft) 10,500

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	0	0
Roof Framing and Roof Surface	10	0.7
Exterior and Interior Wall Framing	10	1.6
Interior Plaster	30	3.3
Exterior Sheathing and Siding	0	0
Doors	10	0.5
Windows	80	3.8
Foundation and Basement	0	0
Misc.: Stairs, Fireplace, Paint, Trim	15	1.8
TOTAL		11.7

Fig. 6-16. House Damage Summary, House No. III-1



Peak Overpressure (psi) 5.1 Positive Phase Impulse (psi-msec) ~ 1850
Charge Size (kt) 30.0 Ground Range (ft) 4700

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	100	17.0
Roof Framing and Roof Surface	100	7.0
Exterior and Interior Wall Framing	100	16.0
Interior Plaster	100	11.0
Exterior Sheathing and Siding	100	8.6
Doors	100	4.6
Windows	100	4.8
Foundation and Basement	3	0.6
Misc.: Stairs, Fireplace, Paint, Trim	100	12.0
TOTAL		81.6

Fig. 6-17. House Damage Summary, House No. III-2

Peak Overpressure (psi) 3.6 Positive Phase Impulse (psi-msec) ~ 520
Charge Size (kt) 50.0 Ground Range (ft) 7020

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	10	1.7
Roof Framing and Roof Surface	100	7.0
Exterior and Interior Wall Framing	20	3.2
Interior Plaster	20	2.2
Exterior Sheathing and Siding	10	0.9
Doors	25	1.2
Windows	80	3.8
Foundation and Basement	0	0
Misc.: Stairs, Fireplace, Paint, Trim	25	3.0
TOTAL		23.0

Fig. 6-18. House Damage Summary, House No. IV-1

Peak Overpressure (psi) 8.6
Charge Size (kt) 50.0

Positive Phase Impulse (psi-msec) ~ 920
Ground Range (ft) 4245

DAMAGE SUMMARY

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Floor and Ceiling Framing	60	10.2
Roof Framing and Roof Surface	100	7.0
Exterior and Interior Wall Framing	50	8.0
Interior Plaster	60	6.6
Exterior Sheathing and Siding	50	4.3
Doors	100	4.6
Windows	100	4.8
Foundation and Basement	10	1.9
Misc.: Stairs, Fireplace, Paint, Trim	50	6.0
TOTAL		53.4

Fig. 6-19. House Damage Summary, House No. IV-2

DAMAGE CORRELATION

The data from Figs. 6-1 through 6-19 are summarized in Table 6-2. It is clear from inspection that the percent damage data correlates very poorly with positive phase impulse. Referring to Type I houses alone, houses I-7 and I-10 experienced identical levels of damage (6 percent) although the incident positive phase impulses differed by almost a factor of seven (185 psi-msec compared with 28 psi-msec). Similarly, if all wood frame houses are considered, houses I-8 and III-1 experienced almost the same amount of damage (11 and 12 percent respectively) although incident positive phase impulse differed by more than a factor of five (161 psi-msec compared with 840 psi-msec).

On the other hand, damage appears to correlate reasonably well with either overpressure or scaled ground range ($D/W^{1/3}$). This is borne out by Figs. 6-20 and 6-21. In both figures there appears to be little difference in response for Types I, II or III houses. That is, one and two story ordinary (unstrengthened) wood frame houses and two story masonry houses (without shear walls) appeared to behave essentially the same. Strengthened wood frame houses and houses with heavy shear walls received significantly less damage.

One important aspect of the good correlation of damage with either incident overpressure or scaled ground range is that it implies that damage to these types of structures tends <u>not</u> to be yield dependent. Referring again to houses I-8 and III-1 (or II-1), the former was exposed to blast from the equivalent of about <u>100 tons</u> of TNT, the latter to blast from the equivalent of about <u>30,000 tons</u> of TNT, a difference by a factor of 300. Yet damage levels, overpressure levels, and scaled ground ranges are all reasonably close. Similarly, houses I-7 and I-10 were exposed to blast from explosive charges that differed in size by a factor of almost 400 (1,000,000 lb compared with 2,550 lb) yet damage levels and overpressure levels were identical, and scaled ground ranges were very close (40.0 vs 38.7).

Table 6-2

SUMMARY OF HOUSE DAMAGE

TEST NO.	CHARGE SIZE	GROUND RANGE (ft)	$D/W^{1/3}$* ($ft/lb^{1/3}$)	PEAK OVER-PRESSURE (psi)	APPROXIMATE POSITIVE PHASE IMPULSE (psi-msec)	DAMAGE QUANTITY (%)
I-1	16.2 kt	7500	29.6	1.8	900	14
2	16.2 kt	3500	13.8	5.0	1750	82
3	30.0 kt	5500	17.7	4.0	1630	36
4	30.0 kt	7800	25.1	2.6	1150	18
5	10,000 lb TNT	865	40.2	1.3	47	5
6	10,000 lb TNT	865	40.2	1.2	44	7
7	500 ton TNT	4000	40.0	1.1	185	6
8	100 ton AN/FO**	1660	28.4	1.6	161	11
9	500 ton TNT	2256	22.7	2.7	340	25
10	2550 lb TNT	528	38.7	1.1	28	6
11	3500 lb TNT	528	34.8	1.3	46	8
II-1	30 kt	10500	33.9	1.9	840	11
2	30 kt	4700	15.2	5.1	1850	81
3	2550 lb TNT	528	38.7	1.1	28	6
4	3500 lb TNT	528	34.8	1.3	46	7
III-1	30 kt	10500	33.9	1.9	840	12
2	30 kt	4700	15.2	5.1	1850	82
IV-1	50 kt	7020	19.1	3.6	520	23
2	50 kt	4245	11.5	8.6	920	53

* Scaling for nuclear bursts assumes 50 percent nuclear-to-TNT efficiency, i.e., 1 kt nuclear is equivalent to 1 x 10^6 lb TNT.

** Assumed equivalent to TNT.

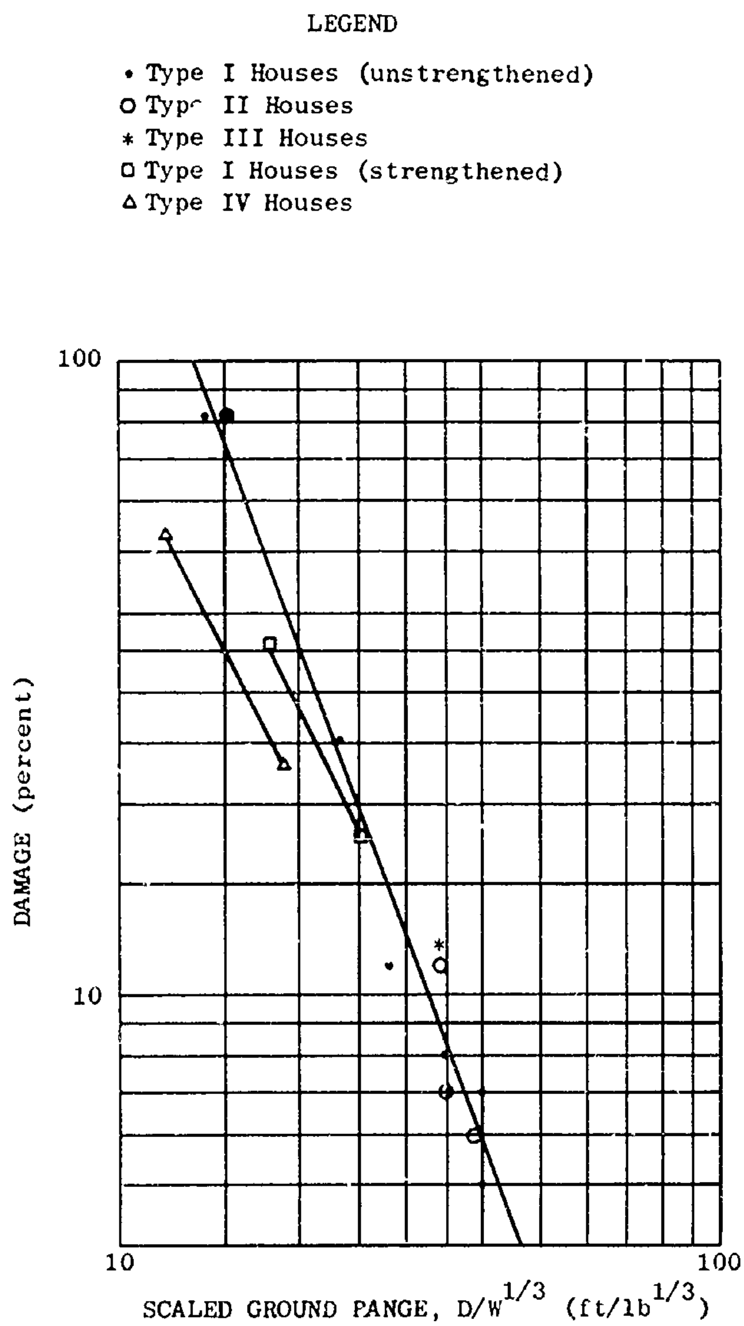


Fig. 6-20. Percent Damage vs Scaled Ground Range

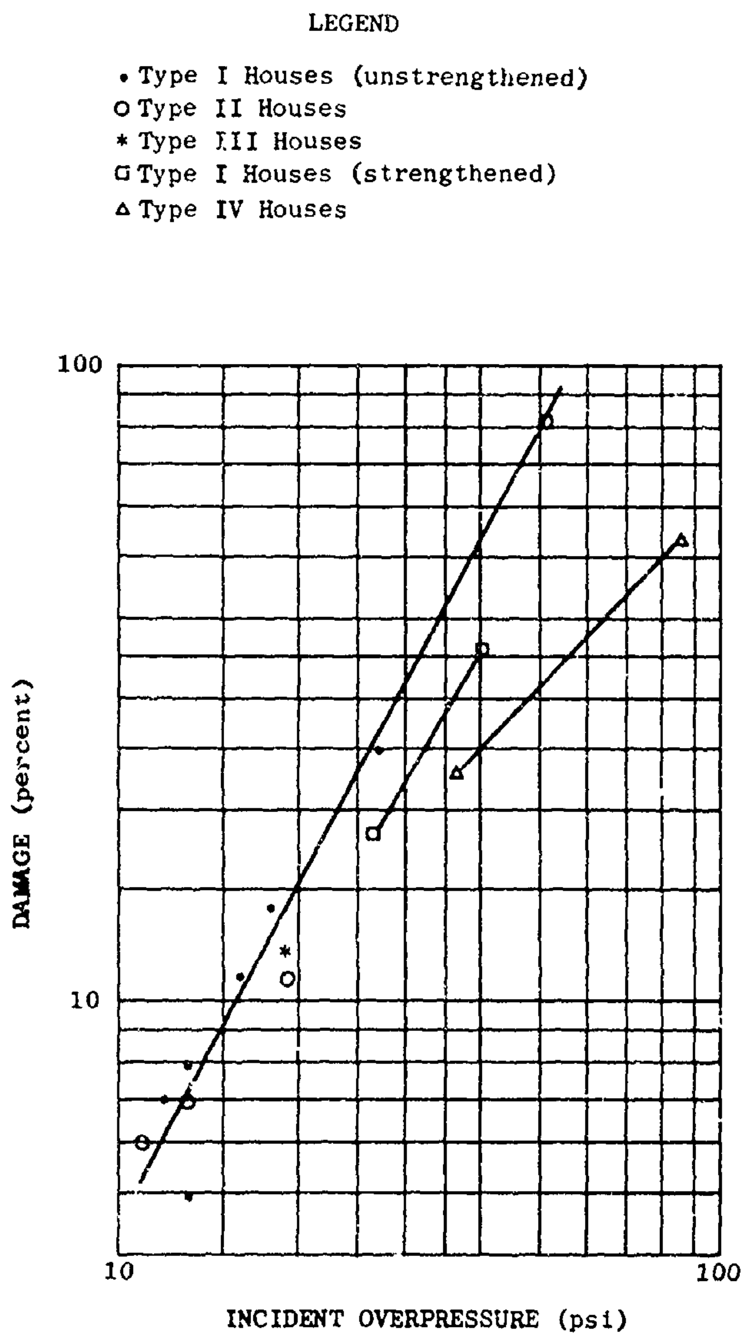


Fig. 6-21. Percent Damage vs Incident Overpressure (psi)

Section 7

IMPORTANCE OF DAMAGE
(Subjective Assessment)

In the preceding section, techniques were developed for determining, in a quantitative, objective way, the amount of damage experienced by a house. Whether such damage is or is not important is much more difficult to determine. Damage data must be treated in a use-oriented manner, which inherently makes it subjective, because the utility of a constructed facility is strictly in the eyes of the user. A temporary occupant of a damaged house in Southern California in the summer time who is seeking shelter and will not rebuild the house, doesn't really care whether the house has a gas supply, or has windows or a roof (as long as it will not collapse). On the other hand the same person will care about the gas supply, windows and roof if the same house is in Minneapolis during a winter snow storm.

Because of the inherent subjectivity, this topic — the importance of damage — is treated in an academic framework more than the very pragmatic framework of the previous section on damage quantities. The subjective evaluation does, however, allow the user of this report to put house damage into a Bayesian Statistical Decision theory format to model possible disaster postures and scenarios.

The approaches to be discussed need not be restricted to nuclear disasters nor to houses alone and therefore in this section the context is broadened to consideration of disasters other than nuclear war and to consideration of structures in general.

It is assumed that this report is being prepared for some future decision maker to use in a process leading to a decision, i.e., to move, burn, evacuate, etc. Thus, the purpose of this material is to create some utility function that will permit a logically consistant decision to be made between certain actions. To accomplish this, any value or utility scale could be selected (A, B, C ..., or 0 to 1, or 0 to 100, or dollars as is done in the preceding section).

THE PROBLEM

The basic problem is to provide a damage assessment of constructed facilities, which have been damaged by some natural and/or man-made disaster.

The concepts will apply to virtually any disaster, i.e., earthquakes, hurricanes, tornados, hail storms, dust storms, industrial explosions, nuclear attack, floods, forest fires, snow storms, etc.

Even on a single disaster, a utility scale can be very subjective. For example, the only structure standing in a small town after a tornado is the new gymnasium of the local high school. To the Red Cross team, this is of great value (high utility) but to the basketball coach, it is of little utility since there is no school or student body to use it. This example also points to the temporal nature of damage assessment, and the fact that measures other than dollars might be needed. The ultimate utility measure of damage by the community at large would be the dollar cost of rebuilding the entire community, but the immediate value to the Red Cross of damaged but usable facilities would not be dollars. Another temporal aspect which must be considered is the time of the year since the weather would affect utility.

Finally, the scope of a disaster can affect how its effects are assessed. Damage from a local disaster will in all probability be repaired, hence a dollar assessment of damage is useful. However, damage caused by a regional or larger disaster (the "Dust Bowl" of the 1930's, or a nuclear attack) may never be repaired, hence a dollar assessment of damage may be meaningless.

Thus, it may be more meaningful to construct our utility scale on a post-disaster use criterion as opposed to a pre-disaster dollar or use criterion. Hence, in assessing damage, it is proposed herein to measure the utility of a constructed facility only by its post-disaster use. For example, in the case of a nuclear disaster, if a frame house was undamaged by direct effects of blast and thermal radiation but was subjected to heavy fallout, the house would have little utility until the fallout sufficiently decayed, then it might have a very high utility. In order to evaluate damage then, one must establish the utility of a facility by its function.

Utility as a Function of Use

First, merely listing a few constructed facilities and their uses helps to establish some system of utility.

Uses of a House

a. To keep dry.
b. To keep warm.
c. A place to sleep.
d. A place to eat and drink.
e. A place to cook.
f. A place to entertain, etc.

Obviously if the deficiency in a dwelling is that it has no gas supply, its utility is less than perfect. (The occupier may be cold, unable to cook, etc.) Hence, each human need gives rise to a utility of a dwelling.

Utility of an Office Building

a. To keep dry.
b. To keep warm.
c. A place to work.
d. A place to eat.
e. A place to drink, etc.

Utility of a Storm Drain

a. Provide a path for storm runoff.
b. Provide protection, etc.

The above list is very brief and only intended to suggest that utilities can vary widely. For example, the utility of a frame dwelling for protection against an oncoming tornado would be very low, i.e., of little value as a shelter — the prime use of a dwelling. However, the utility of a large storm drain for this purpose could be very high (if there were little or no water in the drain, of course) hence it would have a high near-term utility. On the other hand, this storm drain would be of little use as a long-term dwelling, while a house would. Similar considerations should be made in determining the utility of a house or storm drain subjected to an overpressure of, say, 5 psi from a nuclear explosion.

EVALUATING HOUSE DAMAGE

To establish the relative damage of a house, we will first establish a uniform scale, say 0 to 100, for each function of a house, then operate on this with a weighting factor for the relative importance of each item.

Item	Functions (descending importance)
1. Roof	Dry, warm
2. Windows and doors	Warm, dry,
3. Walls	Warm, dry, protected
4. Basement, chimney, etc.	Warm, cook
5. Electric power	Cook
6. Gas	Heat
7. Water	Drink, bath, toilet
8. Sewer	Toilet

Now an evaluator could go through a building in a reasonably short time and rate the above. Let us say a residential wood frame house was subjected to a 2 psi overpressure in a nationwide disaster. The assessor may evaluate the house for a dwelling unit (no fallout assumed) with the techniques of the preceding section and find:

Item	Condition Table % Intact
1. Roof	60
2. Windows and doors	10
3. Walls	90
4. Basement, chimney, etc.	20
5. Electric power	100
6. Gas	0
7. Water	100
8. Sewer	100

Next, let us assume that the total utility of the house is 100. Further, let us consider two climatical situations:

Situation 1

The time is May in San Diego, California.

Situation 2

The time in January in Minneapolis, Minnesota.

The next step is purely subjective; it is to evaluate and distribute relative values (totaling 100 Rasbuetniks*) for the two situations. This part of the effort is most certainly a matter of judgment and subject to criticism, but a decision maker must face questions of this sort in a damage assessment. The values assigned to a house in the two situations are shown in Table 7-1.

Table 7-1

VALUE TABLE FOR A HOUSE

ITEM	SITUATION 1 (Ras)	SITUATION 2 (Ras)
Roof	5	20
Windows and doors	4	15
Walls	3	15
Basement, chimney, etc.	3	10
Electric power	30	10
Gas (heat)	5	20
Water	30	5
Sewer	15	5
TOTAL	100	100

To evaluate the utility of the two situations, we multiply the condition (a physical assessment) by the relative value (utility) and sum, as shown in Table 7-2.

* The emphasis here is that dollars may not be an appropriate measure of utility.

Table 7-2

UTILITY TABLE FOR A HOUSE

ITEM	UTILITY SITUATION 1	UTILITY SITUATION 2
Roof	3.0	12.0
Windows and doors	0.4	1.5
Walls	2.7	13.5
Basement, chimney, etc.	0.6	2.0
Electric power	30.0	10.0
Gas (heat)		
Water	30.0	5.0
Sewer	15.0	5.0
TOTAL	81.7	49.0

The utility of the house in Situation 1 is obviously 1.7 times higher than the utility in Situation 2. Further, an assessor could establish the utility of many buildings in a single situation to pick superior alternatives. It is also obvious that if the condition of the dwelling were due to a local disaster, say to a gas main explosion, the utility would be basically the same in either situation, because the resident could be moved to a motel and the house repaired.

If a decision maker could determine or assign probabilities to situations, he then could treat a whole spectrum of disasters, disaster evaluations, and utility outcomes, i.e., he could then use a war game approach to disaster planning.

The foregoing exercise at least provides a groundwork for damage assessment from the user's view plus providing the mechanism for further studies on disaster gaming.

SUBJECTIVE ASSESSMENT OF OBSERVED HOUSE DAMAGE

In the preceding section, rather detailed evaluations of house damage was provided by using the dollar value of the item and the portion of the item

damaged, i.e., 20 percent roof damaged, etc. The item breakout in that section was made because of construction convenience and not use, but it is interesting to note that a use breakdown has a similar appearance. Thus, it seems that the subjectivist could use the objectivist's data to establish the damage level (note: not the value, which is subjective).

As an exercise, let us use the objective evaluation for the Type I house as the input to a subjective analysis.

Table 7-3 illustrates the relative objective value of each component of the house (based on 100 percent), the grouping to be used in the subjective analysis, and the objective value for each subjective group. This now allows us to use the objective data to establish the damage (in percent) sustained by the subjective or use elements. Table 7-4, for house I-1, shows details of the damage calculations for the house and Table 7-5 summarizes the calculations for houses I-1 through I-11, and also gives the incident overpressure for each test, the correlating parameter to be used.

Table 7-3

RELATIVE OBJECTIVE VALUE OF HOUSE COMPONENTS

ITEM (Objective List)	OBJECTIVE VALUE (% of Total)	SUBJECTIVE GROUP	OBJECTIVE VALUE
Roof framing and roof surface	7.0	Roof	7.0
Doors	4.6	Windows & Doors	35.6
Windows	4.8		
Exterior and interior wall framing	16.0	Walls	9.4
Interior plaster	11.0		
Exterior sheathing and siding	8.6		
Floor and ceiling framing	17.0	Misc	48.0
Foundation and basement	19.0		
Miscellaneous			
Stairs, fireplace, paint, trim	12.0		
TOTAL	100.0		

Table 7-4

DETAILS OF DAMAGE CALCULATIONS FOR HOUSE I-1

OBJECTIVE GROUP	PERCENT DAMAGE	OBJECTIVE VALUE[2]	DAMAGE[3]	SUBJECTIVE GROUP	DAMAGE FOR SUBJECTIVE GROUPS	OBJECTIVE VALUE[2]	PERCENT DAMAGE[4]
Roof framing and roof surface	35	7.0	2.5	Roof	2.5	7.0	35.0
Doors	50	4.6	2.3	Windows & Doors	6.5	35.6	69.0
Windows	88	4.8	4.2				
Exterior and interior wall framing	9	13.0	1.4	Walls	2.0	9.4	5.6
Interior plaster	5	11.0	0.6				
Exterior sheathing and siding	0	8.6	0				
Floor and ceiling framing	12	17.0	2.0	Misc	2.7	48.0	5.6
Foundation and basement	2	19.0	0				
Misc, stairs, fireplace, paint, trim	6	12.0	0.7				
TOTAL		100.0	13.7		19.7		

1. Peak overpressure (psi) 1.8, positive phase impulse (psi-msec) 900, charge size 16.2 kt, ground range 7,500 ft.
2. From Table 7-1.
3. (% damage) x (objective value).
4. (damage for each group)/(objective value).

Table 7-5

OBJECTIVE DAMAGE TABLE IN PERCENT

HOUSE	SUBJECTIVE ITEM			
	ROOF 8 33	DOORS & WINDOWS 7 25	WALLS 5 25	MISC 5 17
I-1	35	69	5.6	5.6
I-2	100	100	100.0	62.0
I-5	1	32	2.0	3.0
I-6	3	40	2.0	4.0
I-7	14	33	3.0	1.0
I-8	27	36	11.5	3.0
I-9	60	81	27.5	7.5
I-10	9	34	2.5	2.0
I-11	12	46	5.6	2.0

Note: I-3 and I-4 neglected since they were strengthened versions.

Now recall that Situation 1 is May in San Diego, California, and Situation 2 is January in Minneapolis, Minnesota. In both cases, we are considering a widespread nuclear disaster without fallout.

Out next task is to establish a subjective table of values for the items of interest in each situation. Reference to Table 7-1, the value table for a house shows that the relative value of the structure alone (the first four items in the value table) is in a 15 to 60 or 1 to 4 ratio for Situations 1 and 2, respectively. If we assign a total value to the structure alone of 25 Ras for Situation 1 and 100 Ras for Situation 2 and distribute them in essentially the way they were in the value table, we get the values shown in Table 7-6. Table 7-7 shows the subjective assessments for all the houses considered in the two situations along with the overpressure level for each test. Figure 7-1 is a plot of the information from Table 7-5.

Table 7-6

SUBJECTIVE VALUE TABLE
(Values are in Rasbuetniks)

ITEM	SITUATION 1	SITUATION 2
Roof	8	33
Windows and doors	7	25
Walls	5	25
Miscellaneous	5	17
TOTAL	25	100

Table 7-7

SUBJECTIVE ASSESSMENT FOR UTILITY OF STRUCTURE
(Values are in Rasbuetniks)

HOUSE	SITUATION NO.	ROOF	DOORS & WINDOWS	WALLS	MISC	Σ	PRESSURE (psi)
I-1	1	2.8	4.8	0.3	0.3	8.2	1.8
	2	11.6	17.3	1.4	1.0	31.3	
I-2	1	8.0	7.0	5.0	3.1	23.1	5.0
	2	33.0	25.0	25.0	10.5	93.5	
I-5	1	0.1	2.2	0.1	0.2	2.6	1.3
	2	0.3	8.0	0.5	0.5	9.3	
I-6	1	0.2	2.8	0.1	0.2	3.3	1.2
	2	1.0	10.0	0.5	0.7	12.2	
I-7	1	1.1	2.3	0.2	0.1	3.7	1.1
	2	4.6	8.3	0.8	0.2	13.9	
I-8	1	2.2	2.5	0.6	0.2	5.5	1.6
	2	8.9	9.0	2.9	0.5	21.3	
I-9	1	4.8	5.7	1.4	0.4	12.3	2.7
	2	19.8	20.3	6.9	1.3	48.3	
I-10	1	0.7	3.4	0.1	0.1	3.3	1.1
	2	3.0	8.5	0.6	0.3	12.4	
I-11	1	1.0	3.2	0.3	0.1	4.6	1.3
	2	4.0	11.5	1.4	0.3	17.2	

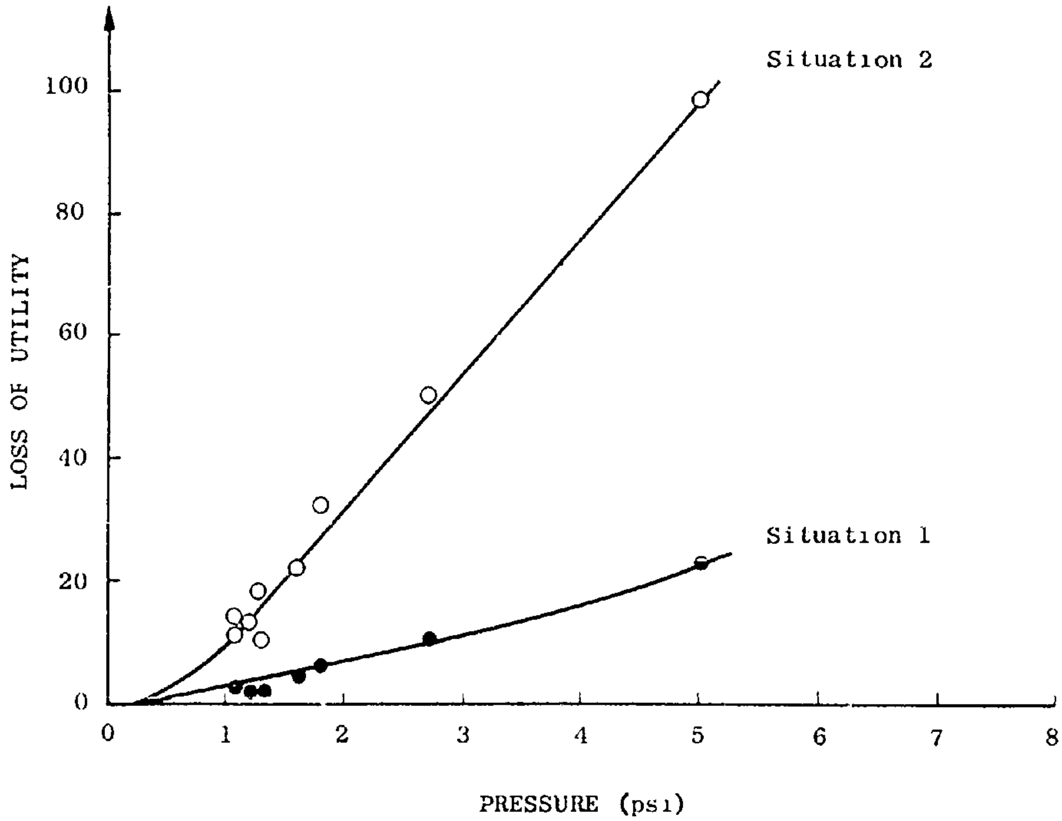


Fig. 7-1. Loss of Utility vs Overpressure for Subjective Analysis

It is clear from the foregoing exercise that the subjective value analysis is not at odds with the objective analysis at all. The "subjective" analysis adds further dimension to the objective analysis and allows the decision maker to adjust for use of the damaged structure other than originally intended if required. It is interesting to observe that the subjective analysis is just as well behaved as the objective analysis when plotted against the overpressure, which is intuitively pleasing. This presentation is far from complete, but it does seem to warrant some further investigation.

Section 8

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Appendix A

CORRELATION OF OBSERVED HOUSE DAMAGE WITH URS SHOCK TUNNEL DATA

For the past several years, URS Research Company has been conducting a program on the loading and response of full-scale (8- x 12-ft) wall panels. These tests, in part, are intended to aid in damage prediction from the blast effects of nuclear weapons.

TEST FACILITY

The shock tunnel is located at the URS Research Company's field laboratory in the San Francisco Bay Area, near the north end of the Golden Gate Bridge. This laboratory is underground, in a former coastal defense gun emplacement complex, and contains approximately 23,000 sq ft of floor space, which is divided into shops, instrumentation rooms, a wave tank, explosives magazines, and the shock tunnel facility. A cutaway view of this laboratory is shown in Fig. A-1.

The shock tunnel occupies approximately 8,000 sq ft of this laboratory and is shown in Fig. A-2. It is rectangular in cross section, 163 ft long, and has walls of reinforced concrete, varying from 3 to 12 ft in thickness. The first 63 ft of the tunnel contains the 3/8-in. thick, 8-ft diameter steel tube that serves as a compression chamber. The remainder of the tunnel consists of an 8-ft long transition section, and a 92-ft long, 8-1/2-ft by 12-ft expansion chamber.

Test specimen mounting positions have been installed in the expansion chamber between 70 and 80 ft from the mouth of the compression chamber. One of these locations is illustrated in Fig. A-3, which shows a brick wall mounted as a simple beam (fixed along the top and bottom, not restrained along the sides). Figure A-4 shows the mounting arrangement for a wall mounted as a simple plate (fixed on all four sides).

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Fig. A-1. Cutaway View of the URS Physical and Engineering Sciences Field Laboratory

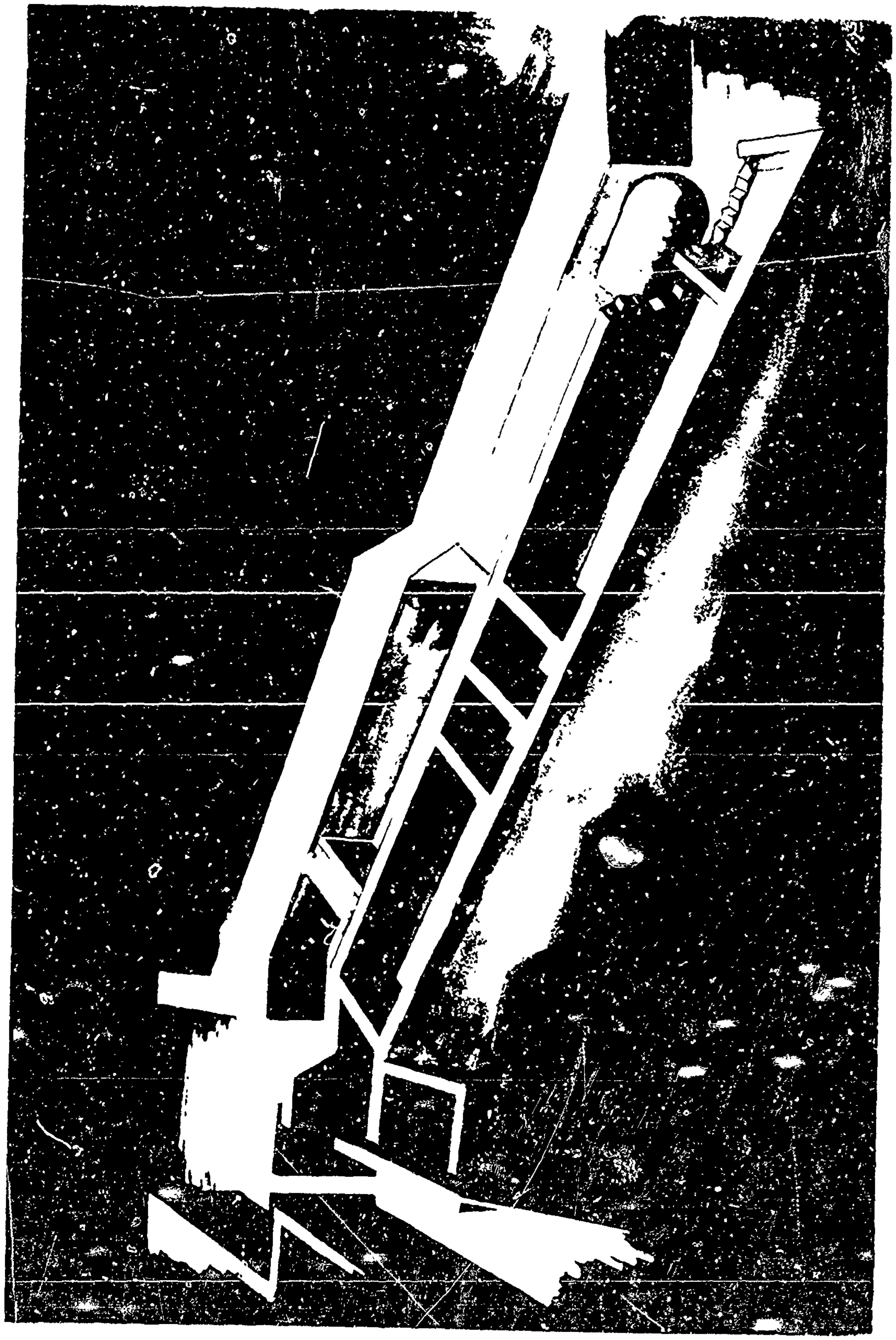


Fig. A-2. Cutaway View of the Shock Tunnel Facility

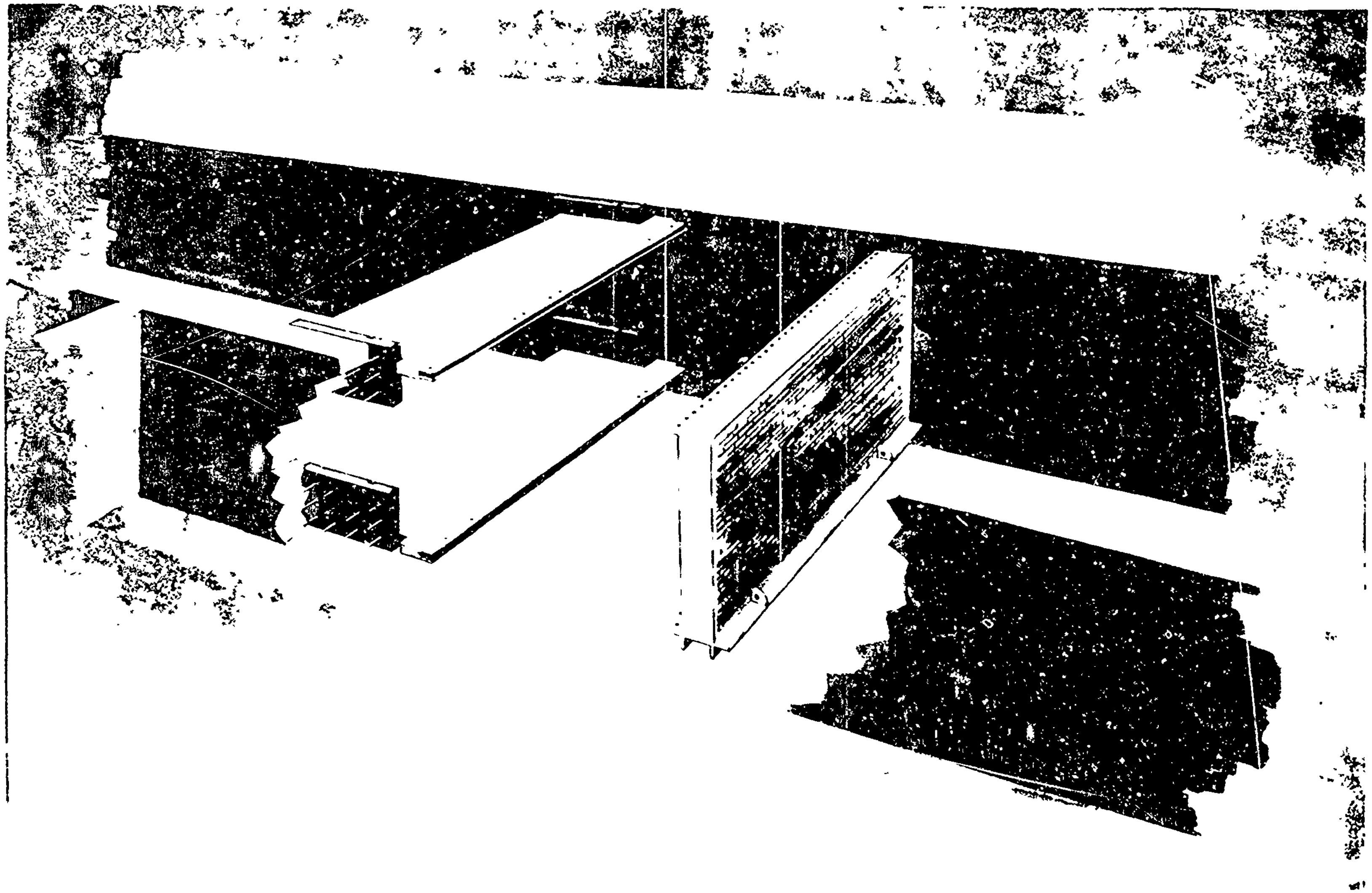


Fig. A-3. Cutaway View of Shock Tunnel Showing Test Panel and Simple Beam Support Condition Hardware

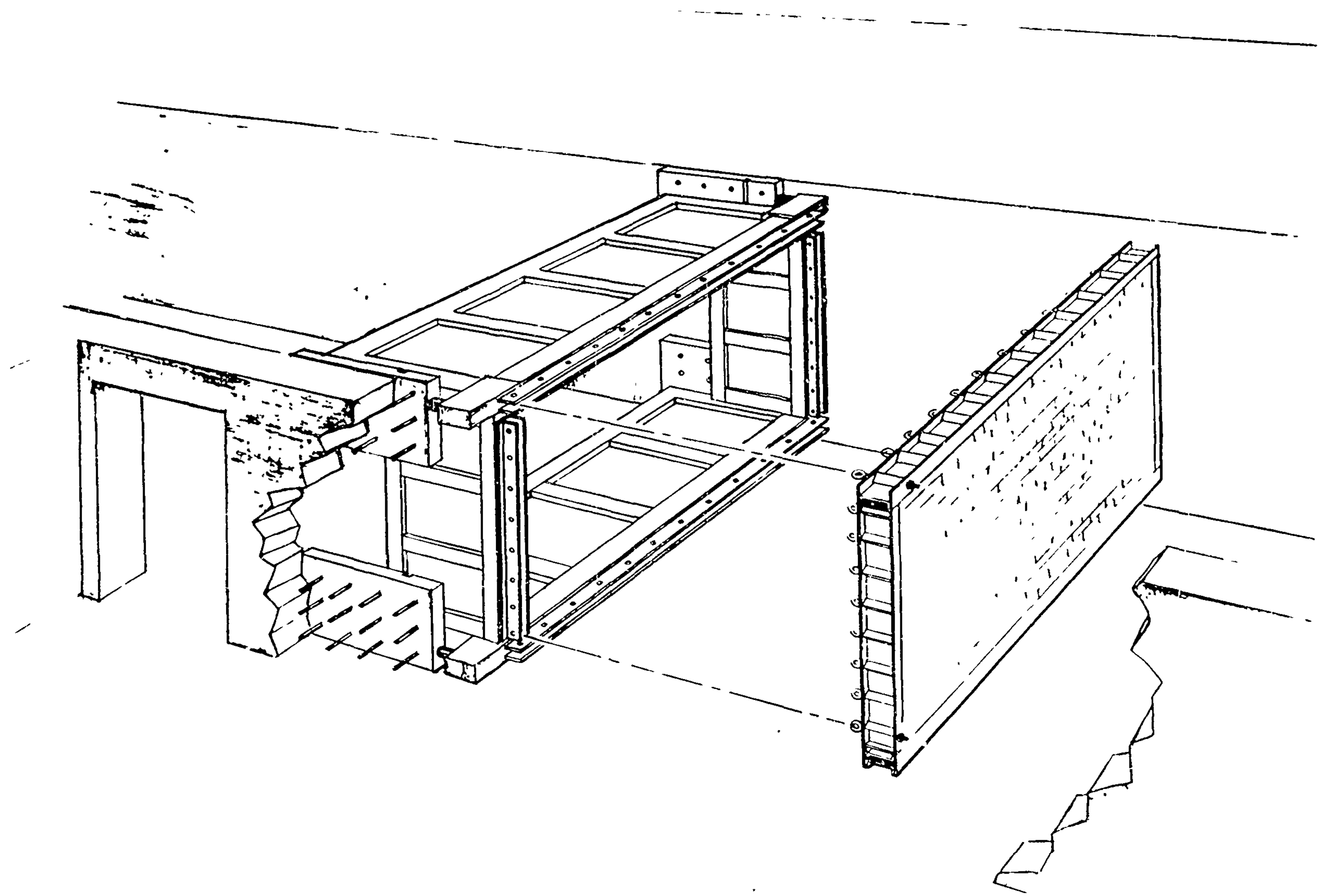


Fig. A-4. Cutaway View of Shock Tunnel Showing Test Panel and Simple Plate Support Condition Hardware

The tunnel is operated as a shock tube by means of the volume detonation technique, with Primacord as the explosive material. In this mode of operation, the Primacord is distributed uniformly throughout the compression chamber. Following the detonation of the Primacord (which proceeds at a rate of about 20,000 ft/sec), a quasi-static pressure is built up very rapidly throughout the entire compression chamber. The expansion of this high-pressure gas into the remaining part of the tunnel generates the desired shock wave.

The shock wave characteristically has a flat top lasting about 40 msec with overpressure decreasing to zero after about 100 msec. Incident (flat-top) overpressures of up to about 10 psi can be generated. Typical shock chamber traces are shown in Fig. A-5. The first two traces are from gages located in the tunnel side wall just ahead of a non-failing wall that completely blocks the tube. Note the two steps, the first step being the incident wave, the second the reflected wave. The remainder of the traces are from gages on the non-failing wall and show reflected pressure only.

TEST RESULTS

To date, the majority of the effort has been placed upon non-reinforced brick wall tests. To provide some correlation of these test data with house damage estimates, a brief summary of some of these data (selected as applicable) is presented in Table A-1. Following the presentation of test data is an illustrative table of expected performance (blast resistance) of various wall types based on the test data.

For plate support conditions, it appears that one can just about double the pressure ranges shown for beams. For example, a fixed plate would require 1.5 to 3.0 psi to fail, or a fixed plate with a window would require 2.4 to 5.2 psi to fail, etc.

Also, 12-in. walls require approximately twice as much pressure to fail as an 8-in. wall, case for case, which should give us a crude damage estimate for a rather broad spectrum of non-reinforced brick walls and buildings.

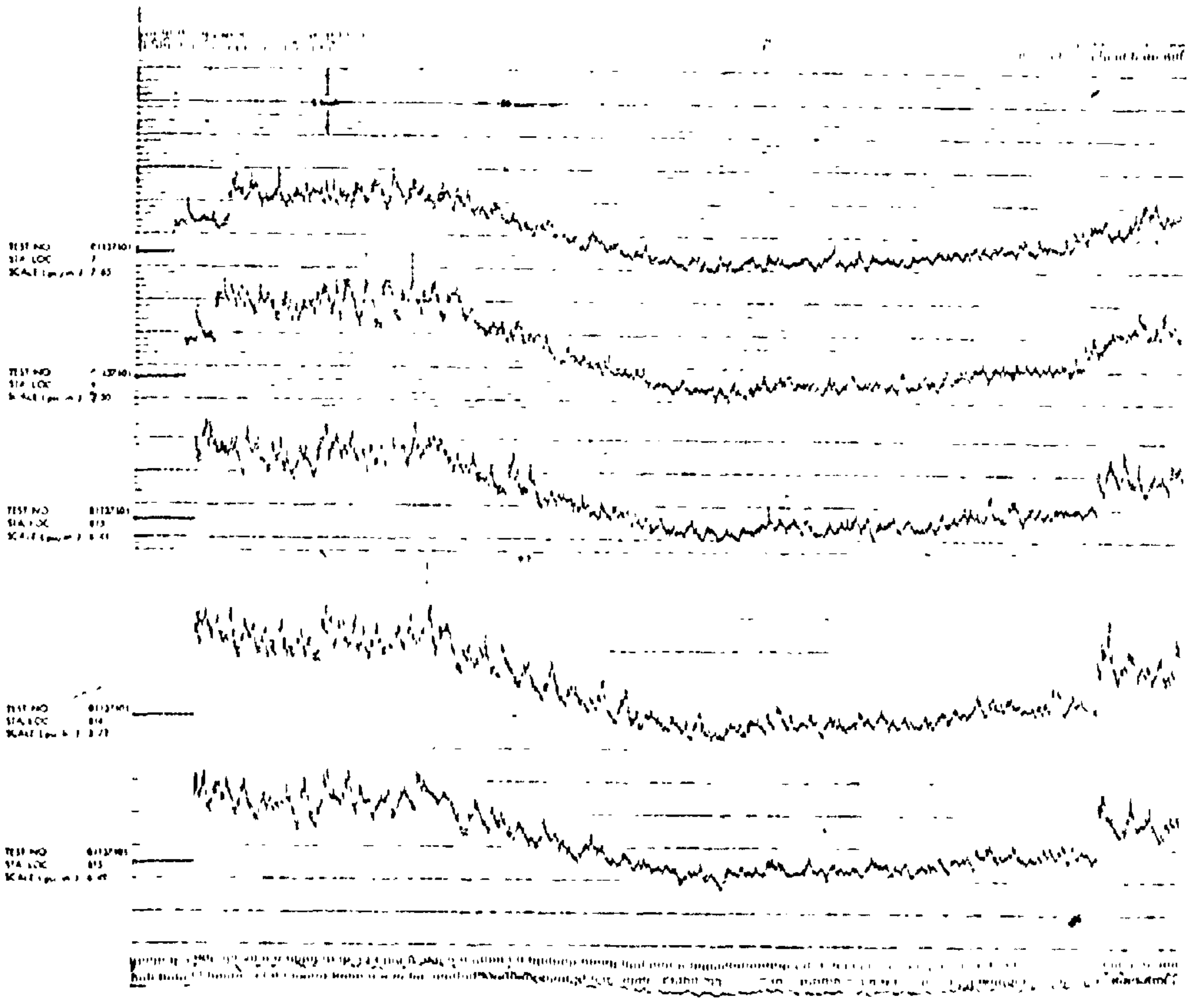


Fig. A-5. Photocopies of Data for 3 Strand Solid Wall Loading Study Test 01-13-71-01

Table A-1

SUMMARY OF SHOCK TUNNEL TEST DATA

TEST NO.	OVER-PRESSURE (psi)	REMARKS
		8-IN. BRICK SIMPLE BEAM WALL
1	1.[illegible]	Wall failed completely.
2	1.7	" " "
3	1.7	" " "
5	1.8	" " "
7	1.8	" " "
21	1.7	" " "
4	4.3	" " "
6	4.4	" " "
20	4.6	" " "
22	3.5	" " "
		12-IN. BRICK SIMPLE BEAM WALL
50	1.9	Wall failed completely.
51	2.1	" " "
52a	0.75	No sign of failure.
52b	0.75	" " " "
52c	0.75	" " " "
52d	2.0	Wall failed completely.
		8-IN. BRICK SIMPLE BEAM WALL WITH PRELOAD (To simulate high curtain bearing walls)
64	0.75	Wall cracked full width but did not come out of frame (preloaded to 16,500 lb*).
64	0.75	Wall completely collapsed.
65	0.75	Wall completely collapsed (preloaded to 16,500 lb).
66	0.75	Wall cracked full width; did not collapse and not reloaded (preloaded to 23,500**).
		8-IN. BRICK SIMPLE BEAM WALL WITH DOORWAY (20% open)
46	1.7	Wall failed completely.
44	4.0	" " "
45	1.8	" " "
48a	0.75	No visible damage.
48b	0.75	" " "
48c	0.75	" " "
48d	1.7	Wall failed completely.

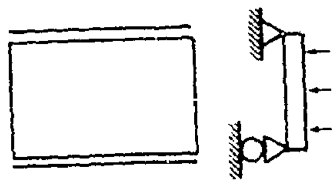
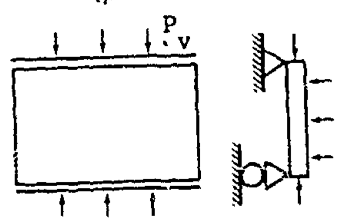
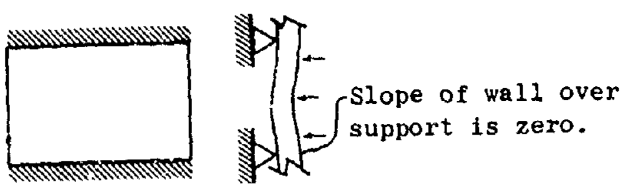
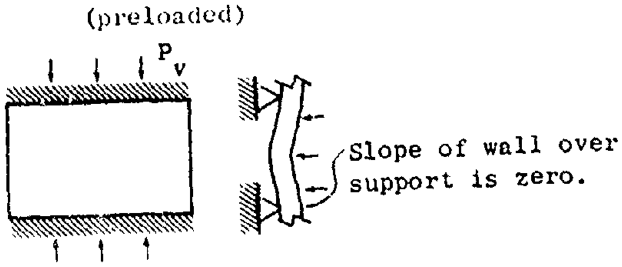
* Equivalent to a two-story curtain wall.

** Equivalent to a three-story curtain wall.

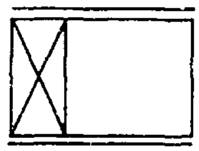
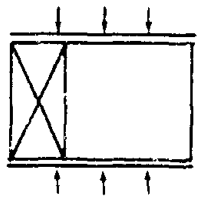
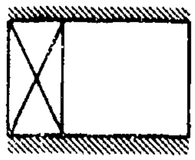
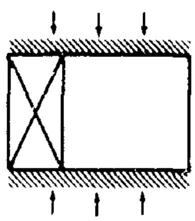
Table A-1 (cont.)

TEST NO.	OVER-PRESSURE (psi)	REMARKS
		8-IN. BRICK SIMPLE PLATE WALL
24a	1.6	Did not collapse but severely cracked in yield line pattern.
24b	1.5	Wall failed completely.
25	1.7	Did not fail completely but a large piece was removed; severely damaged, so not retested.
29a	1.9	Wall did not collapse but cracked in yield line pattern.
29b	2.0	Wall collapsed completely.
28	1.9	" " "
23	4.0	" " "
32	3.9	" " "
33	3.9	" " "

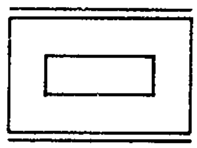
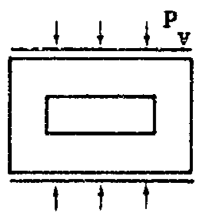
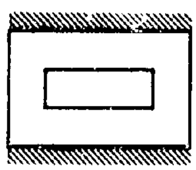
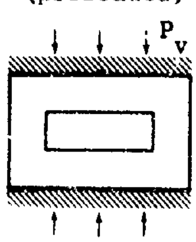
NON-REINFORCED BRICK WALLS (8' x 12' x 8")

Support Conditions	Overpressure Range for Collapse
Solid Wall Simple Beam Support 	0.5 to 1.0 psi (test based)
Solid Wall Simple Beam Support (preloaded) 	0.25 to 1.2 psi (preload range 0 to 1500/lb/ft) (test based)
Solid Wall Fixed (moment resisting) Support 	0.75 to 1.5 psi (estimated)
Solid Wall Fixed (moment resisting) Support (preloaded) 	0.5 to 2.0 psi (estimated)

NON-REINFORCED BRICK WALLS (8' x 12' x 8")

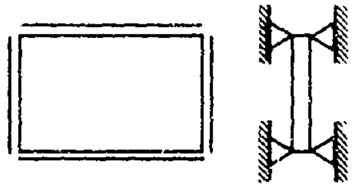
Support Conditions	Overpressure Range for Collapse
Doorway (20% open) Simple Beam Support 	1.0 to 2.0 psi (test based)
Doorway (20% open) Simple Beam Support (preloaded) 	0.75 to 2.4 psi (estimated)
Doorway (20% open) Fixed (moment resisting) Support 	1.5 to 3.0 psi (estimated)
Doorway (20% open) Fixed (moment resisting) Support (preloaded) 	1.2 to 3.4 psi (estimated)

NON-REINFORCED BRICK WALLS (8' x 12' x 8")

Support Conditions	Overpressure Range for Collapse
Window (20% open) Simple Beam Support 	0.75 to 1.75 psi (test based)
Window (20% open) Simple Beam Support (preloaded) 	0.5 to 2.4 psi (estimated)
Window (20% open) Fixed (moment resisting) Support 	1.2 to 2.6 psi (estimated)
Window (20% open) Fixed (moment resisting) Support (preloaded) 	1.0 to 3.0 psi (estimated)

NON-REINFORCED BRICK WALLS (8' x 12' x 8")

Support Conditions	Overpressure Range for Collapse
Simple Plate Supported All Four Sides	1.5 to 2.0 psi (test based)



For example, the front panels of Type II brick houses might be treated as a fixed plate with windows. From the foregoing predictions, one would expect a failure range from 2.4 to 5.2. The damage to test house II-1 was reported as rather minor (11 percent structural damage) at 1.7 psi and to test house II-2 was reported as almost total destruction (82 percent damage) at 5.1 psi. This somewhat crude test and fairly consistent damage estimation with the URS shock tunnel data is quite encouraging.

Another structure one might look at in the light of the URS shock tunnel data is the Type IV buildings (European-brick apartments). These buildings are extremely heavy construction with 12-in. exterior brick walls and interior brick shear walls normal to the loading direction. This type of construction provides walls facing the blast that are 12-in. thick, fixed plate construction with somewhat smaller dimensions than the shock tunnel (10- x 10-ft). From the tunnel data, we would expect a wall about four times as strong as the fixed-simple beam with window or failure in the 4.9 to 10.4 psi range.

House IV-1 was exposed to 3.6 psi and received very little damage to the brickwork (mostly to the timber roof, doors and windows, 23 percent damaged), which would be expected from the shock tunnel data and other house damage data.

House IV-2 was exposed to 8.6 psi and received considerable damage (53 percent) to both brick and timber portions of the house.

It appears that reasonable correlation exists between shock tunnel data and full-scale tests; further, it seems reasonable that these correlations can be refined and improved as the programs continue to mature.

Appendix B

BLAST EFFECTS ON MISCELLANEOUS STRUCTURES DURING OPERATION CASTLE

INTRODUCTION

During the final review of this report the authors were requested to include a discussion of the blast damage to miscellaneous structures which occurred during Shot BRAVO of Operation Castle.

This 14.5 MT nuclear test was conducted in the early 1950's at Bikini ATOLL; a variety of temporary structures were damaged on Peter Island which was about 83,000 ft from ground zero (estimated peak overpressure of 1.3 psi), and on Tara Island 78,000 ft from ground zero (estimated peak overpressure of 1.4 psi).

These structures included a hangar, air operations building, and miscellaneous other structures on Peter Island, and four- and eight-man tents, a mess hall, warehouses and shops on Tare Island.

A number of these damaged structures were very specialized in nature (for example, the hangar, tents and mess hall) and did not fit within the scope of the report. In addition only limited damage information on specific buildings was available (see Ref. 8).

For these reasons this discussion will be limited to the damage sustained by the more conventional structures for which sufficient damage information was available. Mainly, the air operations building on Peter Island and the warehouses on Tare Island.

STRUCTURAL DAMAGE, PETER ISLAND

Air Operations Building, Construction Details

This was a 60- x 30-ft structure with a 2- x 4-in. stud framing, 2 ft o.c. and 2- x 8-in. rafters 1 ft o.c. A 1- x 10-in. ridge beam was supported by

five 4- x 4-in. posts. The siding was 1/2-in. exterior plywood and the roofing was 0.032 gage corrugated aluminum sheet metal secured to 1- x 4-in. nailing strips. The floor slab was estimated to be a 4 in. monolithic slab without reinforcing steel.

Air Operations Building, Structural Damage

A description of the damage to this structure is given in Ref. 8, and was essentially as follows. It was noted that the front side (toward the blast) was caved in, with the studs being broken near their center. Exceptions were those studs located at the corners of the building and door frames which were essentially undamaged. The 2- x 8-in. rafters were broken near the center of their span. Also, about one-half of the sheet metal roofing had been blown off.

Based on the above meager description of damage and one post-test photograph in the report, the damage estimation procedure described in Section 6 was used to estimate the damage sustained by the structure. The first step in this analysis was to estimate the value of the various components which make up the structure. The results of this procedure are shown in Table B-1, where these component values, expressed as a percentage of total value of the structure, are compared with those of the Type I house discussed in the main body of the report.

Using these component value figures, a damage estimate was made which indicated a 41 percent change in total value of the structure caused by the blast damage. The breakdown of each component is as follows:

Table B-1

VALUE OF COMPONENT GROUPS FOR
TYPE I HOUSE AND AIR OPERATIONS BUILDING

ITEM	TYPE I HOUSE (%)	AIR OPERATIONS BUILDING (%)
Floor and Ceiling Framing	17.0	-
Roof Framing and Roof Surface	7.0	35.0
Exterior and Interior Wall Framing	16.0	17.0
Interior Wall Surface	11.0	-
Exterior Wall Surface	8.6	11.0
Foundation*	19.0	20.0
Misc.: Doors, Windows, etc.	21.4	17.0
TOTAL	100.0	100.0

* Includes basement for the Type I house and concrete floor slab for the Air Operations Building.

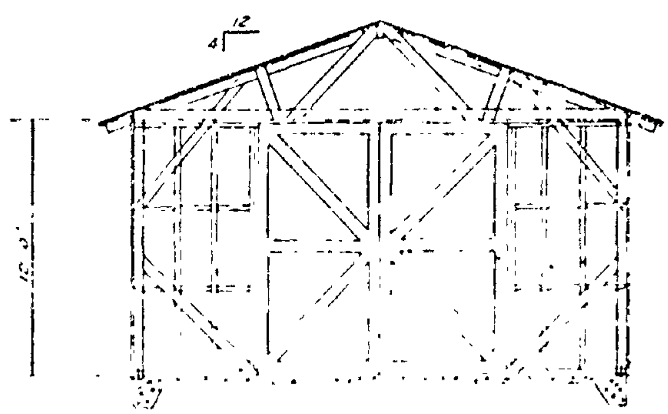
ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Roof Framing	50.0	8.0
Roof Surfacing	50.0	9.0
Exterior and Interior Wall Framing	50.0	8.0
Exterior and Interior Wall Surface	32.0	11.0
Foundation	0	0
Misc.: Doors, Windows, etc.	28.0	0
TOTAL		41.0

STRUCTURAL DAMAGE, TARE ISLAND

Warehouse, Construction Details

Two warehouses were investigated. These were identified in Ref. 8 as the bin storage warehouse and the bulk storage warehouse.

The construction details are shown below. The framing consisted of 2- x 4-in. studs, and 2- x 4-in. trussed rafters with a 2- x 6-in. bottom chard 2 ft o.c. and with a 2- x 4-in. knee bracing 8 ft o.c. The siding was 3/8-in. exterior plywood and the roofing was of corrugated aluminum sheet metal secured to 1- x 4-in. nailing strips. The size of the building was estimated to be 25 x 60 ft.



Warehouses, Structural Damage

Using the same damage estimate procedures that were used for the air operations building the following summary of blast damage was derived.

BIN STORAGE WAREHOUSE

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Roof Framing	85.0	14.0
Roof Surfacing	85.0	16.0
Exterior and Interior Wall Framing	70.0	12.0
Exterior and Interior Wall Surface	80.0	9.0
Foundation	0	0
Misc.: Doors, Windows, etc.	75.0	13.0
TOTAL		64.0

BULK STORAGE WAREHOUSE

ITEM	DAMAGE PERCENT (each element)	CHANGE PERCENT (total value)
Roof Framing	85.0	14.0
Roof Surfacing	90.0	17.0
Exterior and Interior Wall Framing	78.0	13.0
Exterior and Interior Wall Surface	79.0	9.0
Foundation	0	0
Misc.: Doors, Windows, etc.	80.0	13.0
TOTAL		66.0

It should be noted, however, that there is considerable uncertainty in these damage estimates since only minimal damage information was available, i.e., two photographs in Ref. 8.

ANALYSIS AND COMPARISON OF DAMAGE

The damage estimates for these three structures has been plotted on Fig. B-1, a plot of percent damage vs incident overpressure (psi). It will be

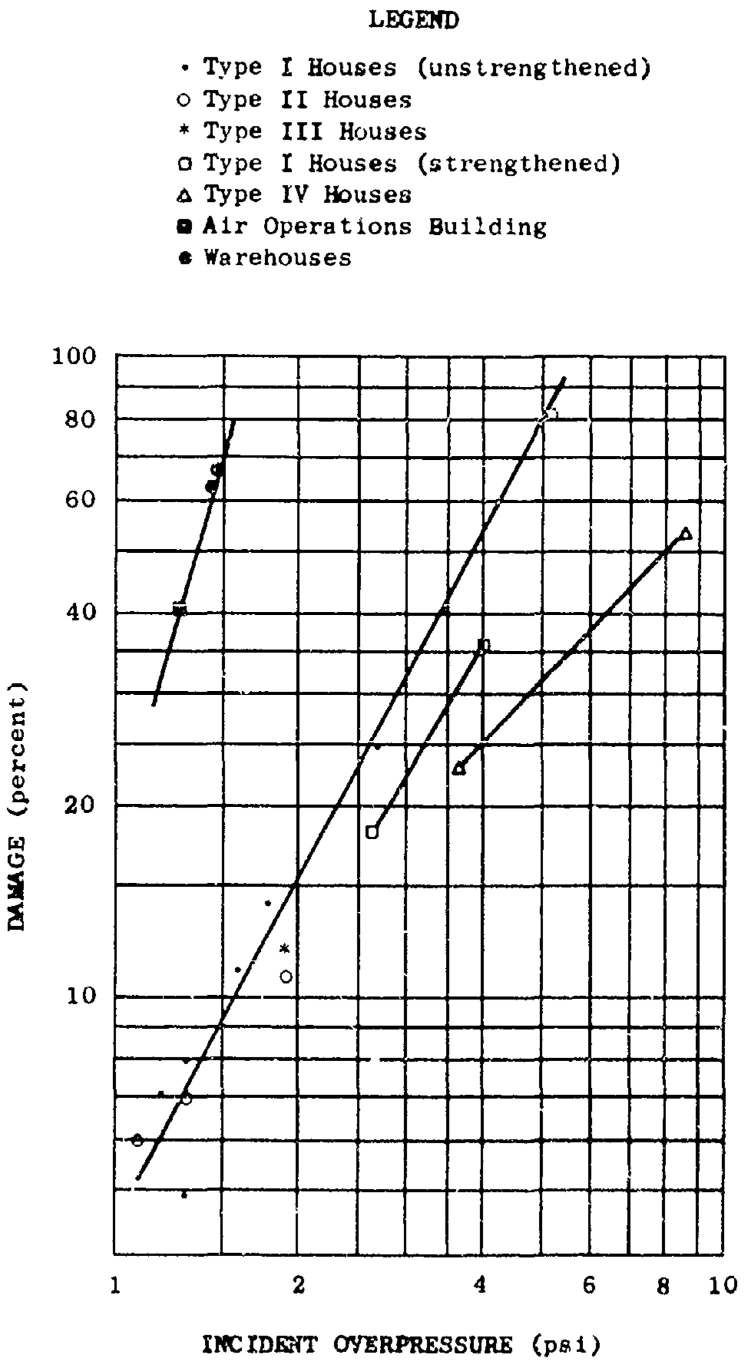


Fig. B-1. Percent Damage vs Incident Overpressure (psi)

noted that these structures are considerably weaker than the Type I house, that is, they sustained more damage at the same overpressure.

A rough analysis of the basic structure of the air operations building indicates that this is true and one would expect a similar order of damage for the Type 1 house and the air operations building at a pressure ratio of 2.25:1 which is fairly close to the 2.6:1 indicated by the damage estimate. It should also be reemphasized that these damage estimates were based on very minimal information and should be used with that fact in mind.